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WCTR Society**

Volume 1

Editors

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ATRG Triennial World Conference on Transportation Research
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The Conference

The ATRG held its Conference at the 8th Triennial World Conference on Transportation Research in Antwerp, Belgium in July 1998.

The 1998 Conference contained 14 aviation and airport sessions. Over 60 research presentations were featured on the topic, Airports & Aviation; these titles are listed on the ATRG website (<http://www.commerce.ubc.ca/atrg/>).

The Proceedings

Once again, on behalf of the Air Transport Research Group, the University of Nebraska at Omaha Aviation Institute has agreed to publish the Proceedings of the ATRG Conference in a four-volume monograph set.

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ATRG President's Foreword

The Air Transport Research Group of the WCTR Society was formally launched as a special interest group at the 7th Triennial WCTR in Sydney, Australia in 1995. Since then, our membership base has expanded rapidly, and now includes over 400 active transportation researchers, policy-makers, industry executives, major corporations and research institutes from 28 countries. Our broad membership base and its strong enthusiasm have pushed the group forward, to continuously initiate new events and projects that benefit the aviation industry and research communities worldwide.

It became a tradition that the ATRG would hold an international conference at least once a year. As you know, the 1997 conference was held in Vancouver, Canada. Over 90 papers, panel discussions and invited speeches were presented. In 1998, the ATRG organized a consecutive stream of 14 aviation sessions at the 8th Triennial WCTR Conference (July 12-17: Antwerp). Again, on 19-21 July, 1998, the ATRG Symposium was organized and executed every successfully by Dr. Aisling Reynolds-Feighan of the University College of Dublin.

As in the past, the Aviation Institute at the University of Nebraska at Omaha (Dr. Brent Bowen, Director of the Institute) has kindly agreed to publish the Proceedings of the 1998 ATRG Dublin Symposium (being co-edited by Dr. Aisling Reynolds-Feighan and Professor Brent Bowen), and the Proceedings of the 1998 WCTR-ATRG Conference (being co-edited by Professors Tae H. Oum and Brent Bowen). On behalf of the ATRG members, I would like to express my sincere appreciation to Professor Brent Bowen and to the staff at the Aviation Institute of UNO for their efforts in publishing these ATRG proceedings. Also, I would like to thank and congratulate all the authors of the papers, for their fine contribution to the conferences and the Proceedings.

Finally, I would like to draw your attention to the ATRG newsletter and the ATRG website (www.commerce.ubc.ca/atrg/) which will keep you informed of the ATRG operations and forthcoming events. On behalf of the ATRG Networking Committee, I would also appreciate it very much if you would encourage others in the field, to sign up for ATRG membership. Thank you for your attention.

Tae H. Oum
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Dr. Brent D. Bowen is Director and Professor, Aviation Institute, University of Nebraska at Omaha. He has been appointed as a Graduate Faculty of the University of Nebraska System-wide Graduate College. Bowen attained his Doctorate in Higher Education and Aviation from Oklahoma State University and a Master of Business Administration degree from Oklahoma City University. His Federal Aviation Administration certifications include Airline Transport Pilot, Certified Flight Instructor, Advanced-Instrument Ground Instructor, Aviation Safety Counselor, and Aerospace Education Counselor. Dr. Bowen's research interests focus on aviation applications of public productivity enhancement and marketing in the areas of service quality evaluation, forecasting, and student recruitment in collegiate aviation programs. He is also well published in areas related to effective teaching. His professional affiliations include the University Aviation Association, Council on Aviation Accreditation, World Aerospace Education Organization, International Air Transportation Research Group, Aerospace Education Association, Alpha Eta Rho International Aviation Fraternity, and the Nebraska Academy of Sciences. He also serves as program director and principal investigator of the National Aeronautics and Space Administration funded Nebraska Space Grant and EPSCoR Programs.

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Strategic Airline Alliances: Complementary vs. Parallel alliances

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Abstract

Strategic alliances have occurred in a broad spectrum of industries including the airline industry. This paper presents a model that examines the effects on market outcome and welfare of two types of strategic airline alliances: complementary vs. parallel alliances. It is identified that the two alliances have different effects on total output and consumer surplus. The complementary alliance is likely to increase total output, while the parallel alliance is likely to decrease it. Consequently, the former increases consumer surplus, while the latter is likely to decrease it. We find sufficient conditions under which each type of alliance improves total welfare. The empirical test results from the trans-Atlantic alliance routes for the 1990-94 period, confirm the theoretical predictions on partners' outputs and total output.



1. INTRODUCTION

Strategic alliances have occurred in a broad spectrum of industries including the automobile, commercial aircraft, electronic equipment, robotics, steel, and telecommunications industries (*Business Week* July 27, 1992; *Economist* September 11, 1993). Among these industries, the airline industry has had a large number of alliances which have been spurred on by regulatory barriers such as the lack of access to domestic markets by foreign carriers, limits on foreign ownership, or simply the fear of being left behind (Gallacher and Odell, 1994).

In order to attract more passengers in an increasingly competitive environment, major international airlines have been seeking to extend the range of their network and access new markets.¹ Some carriers have tried to expand overseas services by adding foreign spokes to their domestic hub cities. Since this approach requires enormous funding to build such a global network, with bilateral restrictions sometimes limiting their ability to expand international services, most international carriers have focused on integrating two or more existing networks through international airline alliances.

Strategic alliances allow carriers to expand the reach of their networks and services to many parts of the world where it may not be economical to do so on their own or where there may be a lack of authority to operate their own flights. These alliances range from simple route-by-route alliances to broad commercial alliances, and to equity alliances.²

Alliances may provide opportunities for partners involved to reduce costs by coordinating activities in some fields: joint use of ground facilities such as lounges, gates and check-in counters; codesharing³ or joint operation; block space sales;⁴ joint advertising and promotion;

¹ In airline markets, there are demand forces such that consumers prefer airlines which serve a large number of points over ones which serve a smaller number of points, with all other factors such as prices held constant (Tretheway and Oum (1992)).

² We analyzed 46 international alliances being formed between the world's top-30 airlines in order to identify the areas of joint activities between alliance partners and measure the extent of coordination. Based on the extent of coordination, 28 cases were classified as simple route-by-route alliances, 9 cases as broad commercial alliances, and 9 cases as equity alliances. The equity alliance is the most advanced and durable form of alliances. It involves strategic linkage between both partners' flight network. One example is the KLM/Northwest alliance signed in January 1993. KLM invested in 25% of Northwest's voting shares and 49% of its equity as of March 1993, and they received antitrust immunity from the U.S. government in November 1992. Although each carrier's management remains separable due to foreign ownership limit, they can closely coordinate. They are able to achieve a high level of integration without fear of legal challenges from competitors and are able to discuss market strategy and pricing.

³ A codesharing agreement is a marketing arrangement between two airlines whereby one airline's designator code is shown on flights operated by its partner airline. For example, Lufthansa has been codesharing on United Airlines' flight between Frankfurt and 25 U.S. interior cities via two of United's hubs (Chicago O'Hare and Washington Dulles). For the effects of codesharing, see Hadrovic (1990) and Gellman Research Associates (1994).

⁴ If two carriers make a block space sale agreement, each carrier can buy a block of seats in the other carrier's flights and resell them to passengers. For example, Air Canada and Korean Air have signed on such an agreement on the Seoul-Vancouver-Toronto route, under which each buys 48 seats from the other's flights

exchange of flight attendants; and so on. As a result, the partners may become more cost-effective and increase their competitiveness.

Alliances also produce several benefits for consumers. Alliance partners can better coordinate flight schedules to minimize travellers' waiting time between flights while providing sufficient time for connections. Joint baggage handling eliminates the need to retrieve and re-check baggage at connecting places, and thus reduces the risk associated with interline handling in which no one carrier has the sole responsibility for the baggage. Consumers' choices can increase due to alliances. For example, consider a passenger who wants to fly from Indianapolis to Lyon. She could fly Indianapolis-Washington, D.C.-Frankfurt-Lyon on United-Lufthansa partners' flights. She could also fly Indianapolis-Pittsburgh-London-Lyon on British Airways-USAir alliance flights. Alternatively, she could fly Indianapolis-Detroit-Amsterdam-Lyon on KLM-Northwest alliance flights. Without the alliances, she would have to interline on several different carriers with great inconvenience.

Although alliances generate benefits for both partners involved and consumers, it may reduce the number of competitors and thus increase the combined market power of alliance partners. As a result, the partners may increase air fares if they behave collusively and abuse their strengthened market power. On the other hand, it is also possible for air fares to decrease since alliances between non-market-leaders can increase their competitiveness against the market leader. By focusing on "complementary" alliances in the trans-Pacific markets, Oum, Park and Zhang (1996) empirically show that the alliances between non-leaders reduce the leader's equilibrium price.

Despite the growing importance of international airline alliances, few researchers have devoted effort to constructing formal models of the alliances.⁵ This paper constructs a formal model to examine the effects on market outcome and economic welfare of different types of alliances: "complementary" and "parallel" alliances. The "complementary" alliance refers to the case where two firms link up their existing networks and build a new complementary network in order to feed traffic to each other. Major strategic alliances such as KLM/Northwest can be regarded as this type of alliance. For example, KLM and Northwest signed the "complementary" alliance by which they were able to connect 88 U.S. cities to 30 European and Middle Eastern cities via Northwest's hubs (Boston, Detroit, and Minneapolis) and KLM's Amsterdam hub, as of December 1994 (U.S. General Accounting Office, 1995).

The "parallel" alliance refers to collaboration between two firms competing on the same routes. Two types of parallel alliances are considered: "no shut-down" and "shut-down" parallel alliances. The difference between the two is that each partner continues to individually provide services on the route in the first type, while two partners integrate their

on the route.

⁵ The international airline issues have been investigated by researchers. The effects on pricing of bilateral agreements were investigated by, among others, Abbott and Thompson (1991), and Maillebiau and Hansen (1995). The effects of alliances have been empirically investigated by, among others, Youssef and Hansen (1994), Gellman Research Associates (1994), and Oum, Park and Zhang (1996).

services in the second type. For example, Air Canada and Korean Air implemented the "no shut-down" parallel alliance on the Vancouver-Seoul route. Delta and Sabena formed the "shut-down" parallel alliance on the New York-Brussels route on which Delta stopped flying and purchased a block of seats from Sabena.

More specifically, this study investigates the following questions: After alliance partners make a particular type of alliance in a specific market, what happens to the partners' and non-aligned competitors' outputs in that market as well as in other markets? What happens to profit for the partners and the competitors due to the alliance? What happens to total output and air fare in that market as well as in other markets? Under which conditions do the alliances improve economic welfare?

In the next section, the Basic Model is considered to compare pre-alliance, complementary alliance, and parallel alliances situations. Section 3 examines the effects of complementary alliance on market outcome and total welfare. Section 4 investigates the effects of two types of parallel alliances on the partners' outputs and total welfare. Section 5 provides the Extend Model by relaxing some conditions assumed in the Basic Model. Section 6 tests some testable predictions associated with the effects on firms' output and total output. Section 7 concludes.

2. THE BASIC MODEL

2.1 Pre-alliance Situation

In order to analyze the effects of alliances on market outcome and economic welfare, we need to construct a pre-alliance situation first where none of airlines have yet to make any type of alliance. As depicted in Figure 1, a network is considered, consisting of three gateway cities located in different countries: A, B and H. There are three origin and destination markets, AH, BH and AB, and three firms (or carriers) are operating in the network. Firm 1 is assumed to serve all three markets (AH, BH and AB) using its hub-and-spoke network. Firms 2 and 3 are assumed to serve AH and BH markets, respectively.⁶

If travellers want to fly from city A and arrive at city B by firm 1's airplanes, they must change airplanes at the hub airport H. Or, they can use two segment flights, separately provided by firms 2 and 3, in order to arrive at their final destination. However, it is assumed that in the pre-alliance situation, travellers do not use multiple carriers' interline connecting services because of poor connections between firms 2 and 3.⁷

⁶ Note that two national carriers are assumed to operate on each route of the network. Since international air services between two cities are mainly decided by bilateral agreements between the two countries involving the two cities, this assumption seems to be reasonable.

⁷ If connections must be made at connecting airports or hubs, less of the traveller's time will be required with a single airline than when the trip involves switching airlines, because a single airline's connecting flights are more likely to reduce waiting time at the connecting airports and lower probability of baggage being lost than multiple airlines' interline connecting flights.

2.2 Complementary Alliance Situation

Consider a situation where firms 2 and 3 make a "complementary" alliance. Both firms jointly provide connecting services for passengers travelling between cities A and B, while continuing to provide local services as before. In order to compete with firm 1's connecting services, the partners enhance quality of their connecting services. For example, the partners can adjust arrival and departure flights to minimize waiting time between flights while providing sufficient time for connections. They can also re-locate departure gates for connecting flights close to arrival gates, coordinate baggage transfer, and cooperate other joint activities at the connecting airport. They agree to share revenues and costs arising from the connecting services.

To examine the effects of this alliance, we need to consider demands and costs. Consider demands first. The "full" price demand model is considered from the viewpoint that each firm's demand in each market depends not only on its air fare, but also its service quality (De Vany, 1974; Panzar, 1979). Assuming that consumers can place a dollar value on service quality, each firm's demand in each market in the complementary alliance situation may be written as

$$Q_{AH}^i = D_{AH}^i(\rho_{AH}^i, \rho_{AH}^j) \text{ for } i=1, 2, i \neq j$$

$$Q_{BH}^i = D_{BH}^i(\rho_{BH}^i, \rho_{BH}^j) \text{ for } i=1, 3, i \neq j$$

$$Q_{AB}^i = D_{AB}^i(\rho_{AB}^i, \rho_{AB}^j) \text{ for } i=1, 2+3, i \neq j$$

where ρ_k^i is the full price of using carrier i 's service in market k , which is the sum of air fare, denoted by p_k^i , and value of service quality. Solving the demand functions for ρ_k^i may yield the following inverse demand functions:

$$\rho_k^i = d_k^i(Q_k^i, Q_k^j) \text{ for } k=AH, BH, AB, i \neq j.$$

We assume that outputs of rival carriers are substitutes in each city-pair market:

$$\frac{\partial d_k^i}{\partial Q_k^j} < 0, \text{ for } k=AH, BH, AB, i \neq j. \quad (1)$$

The value of service quality can be regarded as cost of service quality from the viewpoint of carriers. Two different costs of service quality are considered: (i) schedule delay cost on each route, and (ii) inconvenient connecting cost at the connecting airport.

The schedule delay cost is a passenger's schedule delay time arising from the difference between the passenger's desired departure and actual departure time. Research has found that the schedule delay cost depends largely on the carrier's flight frequency, which in turn depends on its *total traffic* (e.g., Douglas and Miller, 1974). Thus, if Q is the total

passengers carried by carrier i on route k , then the schedule delay cost may be written as $g_k^i(Q)$. It is assumed that $g_k^i(\cdot) < 0$, that is, the schedule delay cost of an airline declines with its traffic on the route. The schedule delay cost for the non-stop services is $g_k^i(Q_k^i + Q_{AB}^i)$ for $k = AH$ and BH , while the schedule delay cost for the connecting service is the sum of the schedule delay cost on each of two local routes, $g_{AH}^i(Q_{AH}^i + Q_{AB}^i) + g_{BH}^i(Q_{BH}^i + Q_{AB}^i)$.

The second component of the cost of service quality is a passenger's inconvenience cost due to connections. Carlton, Landes and Posner (1980) estimate that travellers place an extra cost of \$13-17 (in 1978 dollars) for a single carrier's one-stop connecting services, as compared to its non-stop services. This extra cost for alliance partners' connecting services will be even larger, if the partners' connecting service is inferior to the single carrier's connecting service. For convenience of analysis, without loss of generality, we assume that the inconvenient connecting cost for the single carrier's connections is zero, but that for the partners' connections, denoted by γ , is positive. However, the partners' connecting cost will decrease as the level of their coordination increases at the airport H .

Carrier i 's production cost function on route k may be expressed as $C_k^i(Q)$, implying its round-trip cost of carrying Q passengers on the route. Note that Q represents *total passengers* carried by the airline on the route. This production cost function reflects economies of traffic density, satisfying $C_k^{i'}(Q) > 0$ and $C_k^{i''}(Q) < 0$.⁸

Given these demand and cost specifications, profit function for the non-aligned carrier and aligned partners can be expressed as:

$$\begin{aligned} \Pi^{1c} = & Q_{AH}^1 [d_{AH}^1(Q_{AH}^1, Q_{AH}^2) - g_{AH}^1(Q_{AH}^1 + Q_{AB}^1)] + Q_{BH}^1 [d_{BH}^1(Q_{BH}^1, Q_{BH}^3) - g_{BH}^1(Q_{BH}^1 + Q_{AB}^1)] \\ & + Q_{AB}^1 [d_{AB}^1(Q_{AB}^1, Q_{AB}^{(2+3)}) - g_{AH}^1(Q_{AH}^1 + Q_{AB}^1) - g_{BH}^1(Q_{BH}^1 + Q_{AB}^1)] \\ & - C_{AH}^1(Q_{AH}^1 + Q_{AB}^1) - C_{BH}^1(Q_{BH}^1 + Q_{AB}^1) \end{aligned} \quad (2)$$

$$\begin{aligned} {}^{(2+3)c} = & Q_{AH}^2 [d_{AH}^2(Q_{AH}^1, Q_{AH}^2) - g_{AH}^2(Q_{AH}^2 + Q_{AB}^{(2+3)})] + Q_{BH}^3 [d_{BH}^3(Q_{BH}^1, Q_{BH}^3) - g_{BH}^3(Q_{BH}^3 + Q_{AB}^{(2+3)})] \\ & + Q_{AB}^{(2+3)} [d_{AB}^{(2+3)}(Q_{AB}^1, Q_{AB}^{(2+3)}) - g_{AH}^2(Q_{AH}^2 + Q_{AB}^{(2+3)}) - g_{BH}^3(Q_{BH}^3 + Q_{AB}^{(2+3)}) - \gamma] \\ & - C_{AH}^2(Q_{AH}^2 + Q_{AB}^{(2+3)}) - C_{BH}^3(Q_{BH}^3 + Q_{AB}^{(2+3)}) \end{aligned} \quad (3)$$

⁸ Caves, Christensen and Tretheway (1984) distinguish between economies of traffic density and economies of firm size. Economies of traffic density mean that output is expanded by increasing flight frequency within a given network. Economies of firm size imply that output is expanded by adding points to the network. Many studies reach a common conclusion: roughly constant returns to firm size exist, while sizeable economies of traffic density exist up to fairly large volumes of traffic (See, for example, Caves, Christensen, Tretheway and Windle (1987)).

where superscript *c* stands for complementary alliance.

It can be shown that $\partial^2 \pi^c / \partial Q_{AH}^i \partial Q_{BH}^i = 0$. This implies that there are no network complementarities between local services. We can also show that

$$\frac{\partial^2 \pi^c}{\partial Q_k^i \partial Q_{AB}^i} = -2g_k^{i'}(\cdot) - g_k^{i''}(\cdot) \cdot (Q_k^i + Q_{AB}^i) - C_k^{i''}(\cdot), \quad k = AH, BH. \quad (4)$$

In (4), the first term is positive because an airline's schedule delay cost decreases with its traffic. The second term is positive if *g* is linear or concave. The third term is also positive because of economies of traffic density. (4) can be positive even if *g* is convex. More generally, we assume that (4) is positive, implying that there exist network complementarities between local and connecting services. In other words, a carrier's marginal profit from a local service increases as its connecting passengers increase.

In (1), outputs of rival carriers are assumed to be substitutes in each city-pair market. We further assume that in each market a carrier's marginal profit decreases as the output of the competitor increases:

$$\frac{\partial^2 \pi^c}{\partial Q_k^i \partial Q_k^j} < 0, \quad k = AH, BH, AB, \quad i \neq j, \quad (5)$$

which implies that within each market the outputs of duopolists are "strategic substitutes" in the terms of Bulow, Geanakoplos and Klemperer (1985).

2.3 Parallel Alliance Situation

Next, consider another post-alliance situation where firms 1 and 2 make a "parallel" alliance in a sense that they were competitors in the AH segment of the network before the alliance, but now they coordinate or integrate their operations in that segment. For convenience of notation, among the parallel alliance partners, firm 1 is called as a hub partner, and firm 2 as a non-hub partner. Firm 3 is called as a non-partner.

Two types of parallel alliances are considered. The first is that each partner continues to provide local services in the AH segment and choose their quantities to maximize their joint profits. For example, Air Canada (a hub partner) and Korean Air (a non-hub partner) have implemented this style of parallel alliance on the Seoul-Vancouver-Toronto route since 1993.

Another type is that the partners integrate services in the AH segment in a way that the hub partner continues to provide local services, but the non-hub partner stops producing local services. For simplicity of analysis, it is assumed that the partners equally share revenues and costs arising from the joint services. For example, Delta and Sabena formed this sort of parallel alliance on the New York-Brussels route where Delta stopped non-stop services after the alliance.

Since the non-hub partner shuts down its operation in the second case, the first case is referred to as "no shut-down" parallel alliance, the second as "shut-down" parallel alliance, hereafter. For both cases, firm 3 continues to operate alone in the BH segment as before.

For consistency of analysis, we consider the same demand and cost specifications as used in the complementary alliance. In particular, by using the "full" price demand specification, the inverse demand functions for the parallel alliance may be written as

$$\rho_{AH}^i = d_{AH}^i(Q_{AH}^i, Q_{AH}^j) \text{ for } i=1,2, i \neq j$$

$$\rho_{BH}^i = d_{BH}^i(Q_{BH}^i, Q_{BH}^j) \text{ for } i=1,3, i \neq j$$

$$\rho_{AB}^1 = d_{AB}^1(Q_{AB}^1)$$

where Q_{AH}^2 is positive for the "no shut-down" case; Q_{AH}^2 is zero for the "shut-down" case. We still assume that conditions (1), (4) and (5) hold.

3. EFFECTS OF COMPLEMENTARY ALLIANCE

3.1 Effects on Firms' Outputs and Profits

Let us first analyze the effects of the complementary alliance. We consider an equilibrium that arises when the non-aligned carrier (i.e., firm 1) and the aligned partners (i.e., firms 2+3) play a Cournot game in each market of the network.⁹ By using vectors Q^1 and Q^2 , (2) and (3) can be simplified as

$$\max_{Q^1} \Pi^{1c} = \Pi^{1c}(Q^1, Q^2) \quad (6)$$

$$\max_{Q^2} \Pi^{2c} = \Pi^{2c}(Q^1, Q^2; \gamma) \quad (7)$$

where $Q^i \equiv (Q_{AH}^i, Q_{BH}^i, Q_{AB}^i)$ for $i = 1, 2$. For convenience of notation, superscript 2+3 is replaced by 2. Assume that there exists a "stable" Cournot-Nash equilibrium $(Q^1(\gamma), Q^2(\gamma))$ which satisfies the following first-order conditions for maximization of (6) and (7).¹⁰

⁹ The Cournot assumption is not crucial in the duopoly market. Brander and Zhang (1990) and Oum, Zhang and Zhang (1993), using conjectural variations, find some evidence that airlines in duopoly markets behave like Cournot competitors.

¹⁰ This stability assumption is important. If an equilibrium is not stable, then a slight deviation by one player does not cause the equilibrium to return to that point. The stability of Cournot-Nash equilibrium has been studied by, among others, Seade (1980), Dixit (1986), Slade (1994), and Zhang and Zhang (1996). In particular, Zhang and Zhang (1996) extends single-market conditions for stability of Cournot-Nash equilibria to multimarket conditions.

$$\Pi_1^{1c}(Q^1(\gamma), Q^2(\gamma)) = 0 \quad (8)$$

$$\Pi_2^{2c}(Q^1(\gamma), Q^2(\gamma); \gamma) = 0 \quad (9)$$

Assume that the second-order conditions are also satisfied, i.e., the following Hessian matrices are negative definite for $i = 1, 2$:

$$\Pi_U^{1c} \equiv \begin{bmatrix} \Pi_{AH,AH}^{1c} & \Pi_{AH,BH}^{1c} & \Pi_{AH,AB}^{1c} \\ \Pi_{BH,AH}^{1c} & \Pi_{BH,BH}^{1c} & \Pi_{AB,AB}^{1c} \\ \Pi_{AB,AH}^{1c} & \Pi_{AB,BH}^{1c} & \Pi_{AB,AB}^{1c} \end{bmatrix}$$

With the present specifications, it can be shown that as compared to the pre-alliance situation, firm 1 (the partners, respectively) produces less (more, respectively) output not only in the market where the complementary alliance occurs, but also in the other markets.

Proposition 3-1. Under the complementary alliance conditions, firm 1 produces less output in markets AH, BH and AB, but the alliance partners produce more output in both their local market and the AB market than under the pre-alliance conditions.

Proof. Differentiating (8) and (9) with respect to γ yields

$$\Pi_{11}^{1c} \frac{dQ^1}{d\gamma} + \Pi_{12}^{1c} \frac{dQ^2}{d\gamma} = 0, \quad (10)$$

$$\Pi_{21}^{1c} \frac{dQ^1}{d\gamma} + \Pi_{22}^{1c} \frac{dQ^2}{d\gamma} + \Pi_{2\gamma}^{2c} = 0 \quad (11)$$

where $\Pi_{2\gamma}^{2c} = [0, 0, -1]^T$. Solving (10) and (11) for $(dQ^1/d\gamma, dQ^2/d\gamma)$, we have

$$\frac{dQ^1}{d\gamma} = \left[I - \left(\Pi_{11}^{1c} \right)^{-1} \Pi_{12}^{1c} \left(\Pi_{22}^{2c} \right)^{-1} \Pi_{21}^{2c} \right]^{-1} \left(\Pi_{11}^{1c} \right)^{-1} \Pi_{12}^{1c} \left(\Pi_{22}^{2c} \right)^{-1} \Pi_{2\gamma}^{2c} \quad (12)$$

$$\frac{dQ^2}{d\gamma} = - \left[I - \left(\Pi_{22}^{2c} \right)^{-1} \Pi_{21}^{2c} \left(\Pi_{11}^{1c} \right)^{-1} \Pi_{12}^{1c} \right]^{-1} \left(\Pi_{22}^{2c} \right)^{-1} \Pi_{2\gamma}^{2c} \quad (13)$$

Differentiating (8) with respect to Q^2 yields the following 3-by-3 "derivative" matrix of carrier 1's reaction functions: $R_2^{1c} \equiv \partial R^{1c}(Q^2)/\partial Q^2 = - \left(\Pi_{11}^{1c} \right)^{-1} \Pi_{12}^{1c}$ where $R^{1c}(Q^2(\cdot))$ is carrier 1's reaction function for the aligned partners' outputs. Similarly, a "derivative" matrix of the partners' reaction functions for firm 1's outputs can be defined as $R_1^{2c} \equiv \partial R^{2c}(Q^1)/\partial Q^1 = - \left(\Pi_{22}^{2c} \right)^{-1} \Pi_{21}^{2c}$.

In what follows, we show that every element of R_2^{1c} , R_1^{2c} matrices is negative: First, it turns out that both Hessian inverse matrices are negative matrices. $(\Pi_{11}^{1c})^{-1}$ can be expressed as

$$\frac{1}{|\Pi_{11}^{1c}|} \begin{bmatrix} \Pi_{BH,BH}^{1c} \Pi_{AB,AB}^{1c} - \left(\Pi_{BH,AB}^{1c}\right)^2 & \Pi_{AH,AB}^{1c} \Pi_{BH,AB}^{1c} & -\Pi_{AH,AB}^{1c} \Pi_{BH,BH}^{1c} \\ \Pi_{AB,AH}^{1c} \Pi_{BH,AB}^{1c} & \Pi_{AH,AH}^{1c} \Pi_{AB,AB}^{1c} - \left(\Pi_{AH,AB}^{1c}\right)^2 & -\Pi_{AH,AH}^{1c} \Pi_{BH,AB}^{1c} \\ -\Pi_{AB,AH}^{1c} \Pi_{BH,BH}^{1c} & -\Pi_{AH,AH}^{1c} \Pi_{AB,BH}^{1c} & \Pi_{AH,AH}^{1c} \Pi_{BH,BH}^{1c} \end{bmatrix}$$

By the second-order conditions and the network complementarities condition (4), every element of $(\Pi_{11}^{1c})^{-1}$ is negative. Similarly, $(\Pi_{22}^{2c})^{-1}$ is also negative matrix. Secondly, Π_{12}^{1c} and Π_{21}^{2c} are negative diagonal matrices because of the strategic substitutes condition (5). Thus, both R_2^{1c} and R_1^{2c} are negative matrices.

By using R_2^{1c} and R_1^{2c} , (12) and (13) can be rewritten as

$$\frac{dQ^1}{d\gamma} = -\left[I - R_2^{1c} R_1^{2c}\right]^{-1} R_2^{1c} \left(\Pi_{22}^{2c}\right)^{-1} \Pi_{2\gamma}^{2c} \quad (14)$$

$$\frac{dQ^2}{d\gamma} = -\left[I - R_1^{2c} R_2^{1c}\right]^{-1} \left(\Pi_{22}^{2c}\right)^{-1} \Pi_{2\gamma}^{2c} \quad (15)$$

The stability of Cournot-Nash equilibrium implies that the magnitude of the eigenvalues of matrices $R_2^1 R_1^2$ and $R_1^2 R_2^1$, must be less than one (Zhang and Zhang, 1996). Hence, by the Neumann lemma,¹¹ $\left(I - R_2^{1c} R_1^{2c}\right)^{-1}$ and $\left(I - R_1^{2c} R_2^{1c}\right)^{-1}$ exists and

$$\left(I - R_j^{1c} R_i^{2c}\right)^{-1} = I + \left(R_j^{1c} R_i^{2c}\right) + \left(R_j^{1c} R_i^{2c}\right)^2 + \dots + \left(R_j^{1c} R_i^{2c}\right)^n + \dots \quad \text{for } i=1, 2, i \neq j.$$

Since $R_j^{1c} R_i^{2c}$ is a positive matrix, then $\left(I - R_j^{1c} R_i^{2c}\right)^{-1}$ is also a positive matrix.

Therefore, $dQ^1/d\gamma > 0$ and $dQ^2/d\gamma < 0$ since R_2^{1c} is a negative matrix and $\Pi_{2\gamma}^{2c}$ is a negative vector. Q.E.D.

The intuitive explanations for Proposition 3-1 are as follows: If the partners provide better quality of connecting services in market AB, inconvenience cost (γ) will decrease, which in turn increases connecting traffic for the partners, that is, $dQ_{AB}^{2+3}/d\gamma < 0$. This connecting traffic increase implies that the partners can feed more traffic to each other. As a result,

¹¹ Neumann lemma is that if R is a real square matrix and the magnitude of eigenvalues of R is less than one, then $(I - R)^{-1}$ exists and $(I - R)^{-1} = \sum_{i=0}^{\infty} R^i$. See, for example, Ortega and Rheinboldt (1970, p.45).

schedule delay cost for local non-stop services will decrease (i.e., service quality for the local services increases) and average operating costs on the AH and BH routes will decrease due to economies of traffic density. Consequently, increases in Q_{AB}^{2+3} lead to decreases the partners' air fares in the AH and BH markets, which in turn increases AH and BH traffic as well. Therefore, it is possible that increasing qualities of service and decreasing operating cost are jointly achievable if the partners collaborate very well.

On the other hand, increases in Q_{AB}^{2+3} due to the better coordination decrease Q_{AB}^1 , resulting in increased carrier 1's unit cost on the AH and BH routes and increased schedule delay cost for its local services. As a result of the complementary alliance, carrier 1 decreases output not only in the AB market, but also in the other market.

Although firm 1 reduces its output in markets AH, BH and AB, it does not necessarily imply that it decreases its profit, because its profit is affected not only by its output in these markets, but also by corresponding air fares. Thus, it is worthwhile to investigate whether each firm's profit increases or decreases due to the complementary alliance.

Proposition 3-2. Under the complementary alliance conditions, firm 1 earns less profit, but the alliance partners earn more profit, as compared to the pre-alliance conditions.

Proof. Substituting the Cournot-Nash equilibrium $(Q^1(\gamma), Q^2(\gamma))$ into (6) and (7), and differentiating these with respect to γ , we have

$$\frac{\partial \Pi^{1c}}{\partial \gamma} = \sum_{k=AH}^{AB} \frac{\partial \Pi^{1c}}{\partial Q_k^1} \frac{dQ_k^1}{d\gamma} + \sum_{k=AH}^{AB} \frac{\partial \Pi^{1c}}{\partial Q_k^2} \frac{dQ_k^2}{d\gamma} = \sum_{k=AH}^{AB} \frac{\partial d_k^1}{\partial Q_k^2} \frac{dQ_k^2}{d\gamma} Q_k^1 \quad (16)$$

By the first-order conditions, the first term of the right-hand side of the first equations of (16)

$$\frac{\partial \Pi^{2c}}{\partial \gamma} = \sum_{k=AH}^{AB} \frac{\partial \Pi^{2c}}{\partial Q_k^2} \frac{dQ_k^2}{d\gamma} + \sum_{k=AH}^{AB} \frac{\partial \Pi^{2c}}{\partial Q_k^1} \frac{dQ_k^1}{d\gamma} + \frac{d\Pi^{2c}}{d\gamma} = \sum_{k=AH}^{AB} \frac{\partial d_k^2}{\partial Q_k^1} \frac{dQ_k^1}{d\gamma} Q_k^2 - Q_{AB}^2 \quad (17)$$

and (17) disappears. By condition (1), $\partial \Pi^{1c} / \partial \gamma > 0$ and $\partial \Pi^{2c} / \partial \gamma < 0$. Q.E.D.

3.2 Effects on Market Outcome and Economic Welfare

According to Proposition 3-1, it is not clear whether *total* output in each market increases or decreases due to the complementary alliance since firm 1 decreases output in each market, while the aligned partners increase. Thus, in this section, we examine the effects of the alliances on total output and consumer surplus in each market, and total welfare.

In order to examine changes in *total output* due to the complementary alliance, we further assume that the aligned partners and non-aligned competitors are symmetric and the partners can provide connecting services at the same quality as the non-partner's (i.e., $\gamma = 0$).

Proposition 3-3. For the symmetric case, the complementary alliance results in (i) increased

total output and (ii) decreased "full" price in markets AH, BH, and AB. Therefore, consumers in these markets are better off due to the complementary alliance.
Proof. Let Q be total output vector and $p(Q)$ be corresponding "full" price vector. By definition of Q ,

$$\frac{dQ}{d\gamma} = \frac{dQ^1}{d\gamma} + \frac{dQ^2}{d\gamma} \quad (18)$$

Rearranging (10) and using $R_2^{1c} \equiv -(\Pi_{11}^{1c})^{-1}\Pi_{12}^{1c}$, we can have

$$\frac{dQ^1}{d\gamma} = R_2^{1c} \frac{dQ^2}{d\gamma} \quad (19)$$

Substituting (15) and (19) into (18) yields

$$\frac{dQ}{d\gamma} = -\left[I + R_2^{1c} \left[I - R_1^{2c} R_2^{1c} \right]^{-1} (\Pi_{22}^{2c})^{-1} \Pi_{2\gamma}^{2c} \right] \quad (20)$$

By using the symmetric condition and $R_1^{2c} \equiv -(\Pi_{22}^{2c})^{-1}\Pi_{21}^{2c}$, (20) can be rewritten as

$$\frac{dQ}{d\gamma} \Big|_{\gamma=0} = -\left[I + (\Pi_{22}^{2c})^{-1} \Pi_{21}^{2c} \right]^{-1} (\Pi_{22}^{2c})^{-1} \Pi_{2\gamma}^{2c} \quad (21)$$

Using the result $(AB)^{-1} = B^{-1}A^{-1}$, we can further simplify (21) as follows:

$$\frac{dQ}{d\gamma} \Big|_{\gamma=0} = -\left[\Pi_{22}^{2c} + \Pi_{21}^{2c} \right]^{-1} \Pi_{2\gamma}^{2c} \quad (22)$$

Notice that both Π_{22}^{2c} and Π_{21}^{2c} matrices are negative definite. Consequently, $\Pi_{22}^{2c} + \Pi_{21}^{2c}$ is a negative definite matrix. Its inverse matrix, $(\Pi_{22}^{2c} + \Pi_{21}^{2c})^{-1}$ can be expressed as

$$\frac{1}{|\Pi_{22}^{2c} + \Pi_{21}^{2c}|} \begin{bmatrix} (\Pi_{B,B}^{2c} + \Pi_{B,B}^{2c}) (\Pi_{C,C}^{2c} + \Pi_{C,C}^{2c}) - (\Pi_{B,C}^{2c})^2 & \Pi_{A,C}^{2c} \Pi_{C,B}^{2c} & -\Pi_{A,C}^{2c} (\Pi_{B,C}^{2c} + \Pi_{B,B}^{2c}) \\ \Pi_{C,A}^{2c} \Pi_{B,C}^{2c} & (\Pi_{A,A}^{2c} + \Pi_{A,A}^{2c}) (\Pi_{C,C}^{2c} + \Pi_{C,C}^{2c}) - (\Pi_{A,C}^{2c})^2 & -\Pi_{B,C}^{2c} (\Pi_{A,A}^{2c} + \Pi_{A,A}^{2c}) \\ -\Pi_{C,A}^{2c} (\Pi_{B,B}^{2c} + \Pi_{B,B}^{2c}) & -\Pi_{C,B}^{2c} (\Pi_{A,A}^{2c} + \Pi_{A,A}^{2c}) & (\Pi_{A,A}^{2c} + \Pi_{A,A}^{2c}) (\Pi_{B,B}^{2c} + \Pi_{B,B}^{2c}) \end{bmatrix}$$

where subscripts A, B and, C represent AH, BH, and AB, respectively. Since every element of $(\Pi_{22}^{2c} + \Pi_{21}^{2c})^{-1}$ is strictly negative, the inverse matrix is a negative matrix. Combining it with $\Pi_{2\gamma}^{2c}$ vector implies, we have $dQ/d\gamma \Big|_{\gamma=0} < 0$. Thus, $d\rho(Q)/d\gamma \Big|_{\gamma=0} > 0$. Consequently, consumer surplus in each market increases due to the complementary alliance. *Q.E.D.*

In order to analyze changes in total welfare due to the complementary alliance, we assume a partial equilibrium framework in which consumer demand for air travel in each market is

derived from a utility function which can be approximated by the form

$$\sum_{k=AH}^{AB} U_k(Q_k^1, Q_k^2) + Z$$

where Z is expenditure on a competitively supplied *numeraire* good, and $\partial U_k / \partial Q_k^i = \rho_k^i$. Recall that ρ_k^i is the full price of using carrier i 's service in market k , i.e., $\rho_k^i = p_k^i + g_k^i(\cdot)$.

Then consumer surplus in each market can be written as

$$CS_k = U_k(Q_k^1, Q_k^2) - \rho_k^1 Q_k^1 - \rho_k^2 Q_k^2, \quad (23)$$

and total surplus can be written as

$$W = \sum_{k=AH}^{AB} CS_k + (\Pi^1 + \Pi^2) \quad (24)$$

where W may be interpreted as "World Welfare" if the markets under consideration involves different countries.

Substitution of (2) and (3) into (24) can yield the following expression for W :

$$\begin{aligned} W = & \sum_{k=AH}^{AB} U_k(Q_k^1, Q_k^2) - \sum_{i=1}^2 \left[g_{AH}^i(Q_{AH}^i + Q_{AB}^i) \cdot (Q_{AH}^i + Q_{AB}^i) + g_{BH}^i(Q_{BH}^i + Q_{AB}^i) \cdot (Q_{BH}^i + Q_{AB}^i) \right] \\ & - \sum_{i=1}^2 \left[c_{AH}^i(Q_{AH}^i + Q_{AB}^i) + c_{BH}^i(Q_{BH}^i + Q_{AB}^i) \right] - \gamma Q_{AB}^2 \end{aligned} \quad (25)$$

where again, for simplicity, superscript 2+3 is replaced by 2.

Proposition 3-4. For the symmetric case, total welfare rises due to the complementary alliance.

Proof. Differentiating (25) with respect to γ and using $\partial U_k / \partial Q_k^i = \rho_k^i = p_k^i + g_k^i$, we can show

$$\begin{aligned} \frac{dW}{d\gamma} = & \sum_{i=1}^2 \sum_{k=AH}^{BH} \left[p_k^i - g_k^{i'} \cdot (Q_k^i + Q_{AB}^i) - c_k^{i'} \right] \frac{dQ_k^i}{d\gamma} \\ & + \sum_{i=1}^2 \left[p_{AB}^i - \sum_{k=AH}^{BH} \left(g_k^{i'} \cdot (Q_k^i + Q_{AB}^i) - c_k^{i'} \right) \right] \frac{dQ_{AB}^i}{d\gamma} - \left[Q_{AB}^2 + \gamma \frac{dQ_{AB}^2}{d\gamma} \right]. \end{aligned} \quad (26)$$

Notice the first and second bracketed terms of (26) are positive by the first-order conditions. Since $dQ_k^1/d\gamma > 0$ and $dQ_k^2/d\gamma < 0$ for each market k , the overall effect of the complementary alliance on total welfare is not clear.

However, under the symmetric condition and $\gamma = 0$, (26) can be reduced to

$$\begin{aligned} \frac{dW}{d\gamma} \Big|_{\gamma=0} &= \sum_{k=AH}^{BH} \left[p_k^1 - g_k^{1'} \cdot (Q_k^1 + Q_{AB}^1) - C_k^{1'} \right] \left(\frac{dQ_k^1}{d\gamma} + \frac{dQ_k^2}{d\gamma} \right) \\ &+ \left[p_{AB}^1 - \sum_{k=AH}^{BH} \left(g_k^{1'} \cdot (Q_k^1 + Q_{AB}^1) - C_k^{1'} \right) \right] \left(\frac{dQ_{AB}^1}{d\gamma} + \frac{dQ_{AB}^2}{d\gamma} \right) - Q_{AB}^2. \end{aligned}$$

By the first-order conditions and Proposition 3-3, $dW/d\gamma|_{\gamma=0} < 0$. Q.E.D.

Proposition 3-4 provides sufficient conditions for the complementary alliance to raise welfare. However, welfare can increase even for a small positive γ . For example, in (26), $dW/d\gamma|_{\gamma=0} < 0$ if the partners' markup in each market is greater than firm 1's markup and the $\gamma \cdot (dQ_{AB}^2/d\gamma)$ term is sufficiently small.

4. EFFECTS OF PARALLEL ALLIANCE

4.1 Effects of No Shut-down Parallel Alliance

Let us turn to the effect of the parallel alliances. We first analyze the effect of the "no shut-down" parallel alliance where two partners continue to individually provide local services after their alliance. However, it is hard to directly sign the "overall" effect of the no shut-down parallel alliance since the effect involves switching from one situation (i.e., individual profit maximization) to another (i.e., joint profit maximization). Farrel and Shapiro (1990) use differential techniques in order to avoid similar difficulties faced in the analysis of horizontal merger effects.

To use the differential techniques, we define θ as: $\theta = 1$ for post-parallel alliance; $\theta = 0$ for pre-alliance. We then treat θ as continuous in the range $0 \leq \theta \leq 1$, and assume that carrier i 's output in market k , $Q_k^i(\theta)$, is continuous and differentiable in θ in the entire range. By these assumptions, the overall effect of switching from the pre-alliance to the "no shut-down" parallel alliance can be calculated as the integral of the infinitesimal effect as follows:

$$\Delta Q_k^i(\theta) = Q_k^i(1) - Q_k^i(0) = \int_0^1 [dQ_k^i(\theta)/d\theta] d\theta.$$

It turns out to be easy to sign the infinitesimal effect, $dQ_k^i(\theta)/d\theta$. Consequently, the overall effect, $\Delta Q_k^i(\theta)$, can be determined as well if the sign of the infinitesimal effect remains unchanged in the range, which can be verified.

Based on the demand and cost specifications in Section 2, each firm's post-alliance profit function can be expressed as

$$\max_{Q^1} \Pi^1(Q^1, Q^2, Q^3; \theta) = \Pi^1 + \theta \cdot \Pi^2$$

$$\max_{Q^2} \Pi^{2p}(Q^1, Q^2, Q^3; \theta) \equiv \Pi^2 + \theta \cdot \Pi^1$$

$$\max_{Q^3} \Pi^{3p}(Q^1, Q^3) \equiv \Pi^3$$

where superscript p stands for parallel alliance; $Q^1 \equiv (Q_{AH}^1, Q_{BH}^1, Q_{AB}^1)$, $Q^2 \equiv Q_{AH}^2$, $Q^3 \equiv Q_{BH}^3$; and $\Pi^1 \equiv Q_{AH}^1 [d_{AH}^1(\cdot) - g_{AH}^1(\cdot)] + Q_{BH}^1 [d_{BH}^1(\cdot) - g_{BH}^1(\cdot)] + Q_{AB}^1 [d_{AB}^1(\cdot) - g_{AH}^1(\cdot) - g_{BH}^1(\cdot)] - C_{AH}^1(\cdot) - C_{BH}^1(\cdot)$, $\Pi^2 \equiv Q_{AH}^2 [d_{AH}^2(\cdot) - g_{AH}^2(\cdot)] - C_{AH}^2(\cdot)$, $\Pi^3 \equiv Q_{BH}^3 [d_{BH}^3(\cdot) - g_{BH}^3(\cdot)] - C_{BH}^3(\cdot)$.

We will show that unlike the complementary alliance, parallel alliance partners are more likely to decrease their total output in market AH after their alliance.

Proposition 4-1. If the non-hub partner (i.e., firm 2) produces the same amount of output after the "no shut-down" parallel alliance, then the hub partner (i.e., firm 1) produces less output in all three markets, and the non-partner (i.e., firm 3) produces more output in market BH than under the pre-alliance.

Proof. Since the non-hub partner does not change its output in the parallel alliance, the first-order conditions for firms 1 and 3 may be respectively written as

$$\Pi_1^{1p} = 0, \quad \Pi_3^{3p} = 0.$$

Assuming that there exists a "stable" equilibrium, $(Q^1(\theta), Q^3(\theta))$, which satisfies the first-order conditions for firms 1 and 3, that is,

$$\Pi_1^{1p}(Q^1(\theta), Q^3(\theta); \theta) \equiv 0 \quad (27)$$

$$\Pi_3^{3p}(Q^1(\theta), Q^3(\theta)) \equiv 0 \quad (28)$$

Differentiating (27) and (28) with respect to θ yields

$$\Pi_{11}^{1p} \frac{dQ^1}{d\theta} + \Pi_{13}^{1p} \frac{dQ^3}{d\theta} + \Pi_{1\theta}^{1p} = 0, \quad (29)$$

$$\Pi_{31}^{3p} \frac{dQ^1}{d\theta} + \Pi_{33}^{3p} \frac{dQ^3}{d\theta} = 0 \quad (30)$$

where $\Pi_{1\theta}^{1p} \equiv [Q_{AH}^2 \cdot (\partial d_{AH}^2 / \partial Q_{AH}^1), 0, 0]^T$, the first element of which is negative by condition (1).

Since both $(\Pi_{33}^{3p})^{-1}$ and Π_{31}^{3p} are negative matrices, $dQ^1/d\theta$ and $dQ^3/d\theta$ have opposite signs

(see equation (30)). Now, we show $dQ^1/d\theta < 0$. Solving (29) and (30) for $dQ^1/d\theta$, we have

$$\frac{dQ^1}{d\theta} = - \left[I - R_3^{1p} R_1^{3p} \right]^{-1} \left(\Pi_{11}^{1p} \right)^{-1} \Pi_{10}^{1p} \quad (31)$$

where $R_3^{1p} \equiv - \left(\Pi_{11}^{1p} \right)^{-1} \Pi_{13}^{1p}$ and $R_1^{3p} \equiv - \left(\Pi_{33}^{3p} \right)^{-1} \Pi_{31}^{3p}$ are derivative matrices of firm 1's (firm 3's, respectively) reaction function for firm 3's (firm 1's, respectively) output. Imposing the stability condition on the equilibrium yields that $\left[I - R_3^{1p} R_1^{3p} \right]^{-1}$ is a positive matrix. As shown in Proposition 3-1, every element of $\left(\Pi_{11}^{1p} \right)^{-1}$ is negative because of the second-order conditions and the network complementarities condition (4). Therefore, $dQ^1/d\theta < 0$ and $dQ^3/d\theta > 0$.

Next, we show that the signs of $dQ^1/d\theta < 0$ and $dQ^3/d\theta > 0$ remain unchanged in the entire range of interest. In (31), the third term, Π_{10}^{1p} , remains as negative in the range since the first element of Π_{10}^{1p} is always negative regardless of any value of θ in the range. By similar arguments, the signs of the first and second terms remain unchanged in the region. *Q.E.D.*

Notice that the condition which $\Pi_{10}^{1p} < 0$ plays a crucial role in Proposition 4-1. In fact, $\Pi_{10}^{1p} \equiv \Pi_1^2$, thus implying that firm 2's profit decreases as firm 1 produces more output in market AH. Thus, the intuition behind Proposition 4-1 is that by forming the "no shut-down" parallel alliance and maximizing the joint profit, the hub partner chooses Q^1 with taking account of the negative externalities of the hub partner's output on the non-hub partner's profit. This leads to decreases in the hub partner's output in market AH. Consequently, the hub partner decreases its BH and AB traffic due to the network complementarities.

Similarly, we can show

Proposition 4-2. If the hub partner (i.e., firm 1) produces the same amount of output after the parallel alliance, then the non-hub partner (i.e., firm 2) decreases its output, and the non-partner (i.e., firm 3) produces the same amount of output, as compared to the pre-alliance situation.

The next question naturally arises: what if both Q^1 and Q^2 are chosen endogenously? If the two partners endogenously decides their outputs, they cannot simultaneously increase output in market AH after the parallel alliance.

Proposition 4-3. $dQ^1/d\theta$ and $dQ^2/d\theta$ cannot both be positive.

Proof. Denoting a "stable" equilibrium by $(Q^1(\theta), Q^2(\theta), Q^3(\theta))$, and differentiating the first-order conditions with respect to θ , we have

$$\Pi_{11}^{1p} \frac{dQ^1}{d\theta} + \Pi_{12}^{1p} \frac{dQ^2}{d\theta} + \Pi_{13}^{1p} \frac{dQ^3}{d\theta} + \Pi_{10}^{1p} = 0, \quad (32)$$

$$\Pi_{21}^{2p} \frac{dQ^1}{d\theta} + \Pi_{22}^{2p} \frac{dQ^2}{d\theta} + \Pi_{20}^{2p} = 0, \quad (33)$$

$$\Pi_{31}^{3p} \frac{dQ^1}{d\theta} + \Pi_{33}^{3p} \frac{dQ^3}{d\theta} = 0 \quad (34)$$

where $\Pi_{20}^{2p} = Q_{AH}^1 (\partial d_{AH}^1 / \partial Q_{AH}^2) < 0$.

Again, from (34), it can be easily verified that $dQ^1/d\theta$ and $dQ^3/d\theta$ have opposite signs. Equations (32) and (33) show that $dQ^1/d\theta$ and $dQ^2/d\theta$ are interdependent with each other. Solving (32)-(34) for $dQ^1/d\theta$ and $dQ^2/d\theta$ yields

$$\frac{dQ^1}{d\theta} = -[I - R_3^1 R_1^{3p}]^{-1} (\Pi_{11}^{1p})^{-1} \left(\Pi_{10}^{1p} + \Pi_{12}^{1p} \frac{dQ^2}{d\theta} \right), \quad (35)$$

or

$$\frac{dQ^2}{d\theta} = -(\Pi_{22}^{2p})^{-1} \left(\Pi_{20}^{2p} + \Pi_{21}^{2p} \frac{dQ^1}{d\theta} \right). \quad (36)$$

Since $\Pi_{12}^{1p} < 0$ and $\Pi_{21}^{2p} < 0$ due to the strategic substitutes condition, both $dQ^1/d\theta$ and $dQ^2/d\theta$ cannot be positive in (35) and (36). Q.E.D.

Notice that if $dQ^2/d\theta = 0$, then (35) reduces to (31) and Proposition 4-1 follows. Similarly, if $dQ^1/d\theta = 0$, then (36) can be used to show Proposition 4-2.

Although both $dQ^1/d\theta$ and $dQ^2/d\theta$ cannot simultaneously be positive in (35)-(36), it is possible that both $dQ^1/d\theta$ and $dQ^2/d\theta$ are negative in (35)-(36). This can be illustrated by the following numerical example. Assume that demand is linear as follows:

$$d_k(Q_k^1, Q_k^2) = \alpha - (Q_k^1 + Q_k^2), \quad \text{for } k = AH, BH, AB.$$

Assume further that schedule delay cost, $g_k(\cdot)$, is also linear and that operating cost, $C_k(\cdot)$, is concave:

$$g_k(Q_k^1) = 1 - \delta Q_k^1, \quad C_k(Q_k^1) = Q_k^1 - \frac{\mu}{2} (Q_k^1)^2, \quad \text{for } k = AH, BH, AB \quad (38)$$

where μ represents the extent of increasing returns to traffic density. Given these specifications, the explicit expressions of equilibrium output can be obtained for each firm under the pre-alliance and the "no shut-down" parallel alliance situations. In particular, when $\alpha = 4$, $\delta = 0.03$, $\mu = 0.04$, both of the partners decrease their outputs, while the non-

partner increases its output. More accurately, changes in each firm's output due to the "no shut-down" alliance are $\Delta Q^1 \equiv (\Delta Q_{AH}^1, \Delta Q_{BH}^1, \Delta Q_{AB}^1) = (-0.2142, -0.0009, -0.0119)$; $\Delta Q^2 \equiv \Delta Q_{AH}^2 = -0.1404$; and $\Delta Q^3 \equiv \Delta Q_{BH}^3 = 0.0009$, respectively.

To sum up the effects of the "no shut-down" parallel alliance on each firm's output, the partners' total output is likely to decrease, while the non-partner output may increase (by Proposition 4-1), remain unchanged (by Proposition 4-2), or decrease (by $dQ^1/d\theta > 0$ in Proposition 4-3). Thus, consumer surplus in market AH is likely to decrease due to this type of parallel alliance.

4.2 Effects of Shut-down Parallel Alliance

We now analyze the effects of the second style of parallel alliance where the partners integrate local services in the AH segment in a way that the hub partner continues to provide the local services, but the non-hub partner stops producing the local services. However, it is intractable to compare the pre-alliance and shut-down parallel alliance by using general functions since the number of the first-order conditions for the former is not the same as that for the latter. For tractability of analysis, we impose more structures on the model. First, demands and schedule delay costs for all three markets are assumed to be symmetric. Secondly, in order to use a common cost function, we assume that the distances between cities A and H, and between B and H are the same. Thirdly, we use special functions (37)-(38) for demand, schedule delay cost, and operating cost.¹²

Comparing the solution of the pre-alliance situation to that of the "shut-down" parallel alliance, we first examine the effects of the "shut-down" parallel alliance on each firm's output.

Proposition 4-4. Under the "shut-down" parallel alliance conditions, the partners produce less output in market AH, but produce more output in markets BH and AB, and firm 3 produces less output in its local market BH than under the pre-alliance conditions. The proofs of the "shut-down" parallel alliance are provided in the Appendix. The intuitive reasons for Proposition 4-4 are as follows: First of all, since the AH market is now serviced only by the name of the hub partner, this market becomes a monopoly market. The hub-partner produces more than its pre-alliance output in this market, but less than total pre-alliance output, i.e., $Q_{AH}^{1b} < Q_{AH}^{1p} (= Q_{AH}^{(1+2)p}) < Q_{AH}^{1b} + Q_{AH}^{2b}$. Secondly, the hub partner increases its BH and AB traffic due to the network complementarities. Thirdly, the non-partner will decrease its BH traffic since its reaction function to the hub partner's output in market BH is downward sloping.

Next, the effects on each firm's profit are examined. In general, the post-alliance profit of the non-hub partner (i.e., firm 2) increases when the size of markets (α) is sufficiently large for a given economies of traffic density (μ). Joining the "shut-down" parallel alliance, the

¹² The linear demand and concave operating cost functions are also used in Brueckner and Spiller (1991), Brueckner, Dyer and Spiller (1992), and Nero (1996).

non-hub partner decreases revenue from market AH since total output in this market decreases due to the alliance. But, the non-hub partner becomes more cost-effective by jointly producing the hub partner's connecting services on the AH route. If the size of markets is large enough for the partners to produce a great volume of traffic on the AH route, firm 2's gains from the cost-effectiveness dominate its losses from the decreased revenue.

Proposition 4-5. Under the "shut-down" parallel alliance conditions, the hub partner earns more profit than under the pre-alliance conditions. Given the economies of traffic density, the non-hub partner earns more (less, respectively) profit when the size of markets is sufficiently large (small, respectively) than under the pre-alliance situations. Firm 3 earns less profit, as compared to the pre-alliance conditions.

We next examine the effects of the "shut-down" parallel alliance on total output and consumer surplus in each market. According to Proposition 4-4, passengers in market AH are worse off since total output in this market decreases while the corresponding "full" price increases. Thus, consumer surplus in market AH decreases due to the parallel alliance. However, it is not obvious whether or not consumers in market BH are better off due to the alliance.

Proposition 4-6. The "shut-down" parallel alliance results in (i) increased (decreased, respectively) total output and (ii) decreased (increased, respectively) "full" price in markets BH and AB (market AH, respectively). Therefore, consumers in these markets (this market, respectively) are better off (worse off, respectively) due to the parallel alliance.

Although Proposition 4-6 shows increases in consumer surplus in markets BH and AB due to the parallel alliance, it can be verified that decreases in consumer surplus in market AH dominate the increases in market BH and AB.

To summarize the effects of the "shut-down" parallel alliance on each firm's output, the partners' output decreases in market AH and increases in markets BH and AB, while the non-partner's output decreases. Like the "no shut-down" parallel alliance, consumer surplus in market AH decreases due to the "shut-down" parallel alliance.

5. THE EXTENDED MODEL

The Basic Model have analyzed the effects of three types of alliances on the basis of an assumption that there are no demand shifts due to the alliances. We now extend the Basic Model by taking into account the potential codesharing effect on demand shift. Under a codesharing agreement, one airline's designator code is shown on flights operated by its partner. The codesharing allows the partners to offer a higher frequency service to consumers should the partners maintain or increase their respective frequency. For example, before the alliance, LH and UA provided one daily non-stop service between Washington, D.C. and Frankfurt, respectively. After the alliance, they were able to offer two daily non-stop services on the route thanks to the codesharing. It is therefore possible that demand functions for the partners are shifted up by the codesharing effect.

5.1 Complementary alliance

Assuming that the partners' "full" price demand functions in each market are shifted up due

to the partners' codesharing, the partners' post-alliance (inverse) demand shifts may be written as

$$\rho_k^2 = d_k^2(Q_k^1, Q_k^2) + \xi, \text{ for } k = AH, BH, AB$$

where ξ is an exogenous demand shift due to the codesharing effect.

The post-alliance profit function (6) and (7) can be rewritten as

$$\max_{Q^1} \Pi^{1c} = \Pi^{1c}(Q^1, Q^2) \quad (39)$$

$$\max_{Q^2} \Pi^{2c} = \Pi^{2c}(Q^1, Q^2; \gamma, \xi). \quad (40)$$

In the Basic Model, ξ is set to zero. Assume that there exists a "stable" Cournot-Nash equilibrium, $(Q^1(\gamma, \xi), Q^2(\gamma, \xi))$, satisfying the first-order conditions for (39) and (40). Differentiating the FOCs with respect to ξ and solving for $\partial Q^1/\partial \xi$ and $\partial Q^2/\partial \xi$, we have

$$\frac{\partial Q^1}{\partial \xi} = -[I - R_2^{1c} R_1^{2c}]^{-1} R_2^{1c} (\Pi_{22}^{2c})^{-1} \Pi_{2\xi}^{2c} \quad (41)$$

$$\frac{\partial Q^2}{\partial \xi} = -[I - R_1^{2c} R_2^{1c}]^{-1} (\Pi_{22}^{2c})^{-1} \Pi_{2\xi}^{2c} \quad (42)$$

where $\Pi_{2\xi}^{2c} = [1, 1, 1]^T$. Since $[I - R_j^{1c} R_i^{2c}]^{-1} > 0$, $R_2^{1c} < 0$, and $(\Pi_{22}^{2c})^{-1} < 0$, then $\partial Q^1/\partial \xi < 0$ and $\partial Q^2/\partial \xi > 0$. This implies that the codesharing effect on the partners' demand shifts does not change the propositions derived from the Basic Model. In particular, for a given γ , under the demand shift situation, (i) the partners (non-partner, respectively) produce more output (less output, respectively) in the three markets, and (ii) total output in each market increases more than under the Basic Model situation.

What if the non-partner's demand function is also shifted up due to the partners' codesharing effect? If the partners cannot fully capture demands created by the codesharing effect, some of the demands may be left over to the non-partner. We shall assume that the non-partner's "full" price demand function is slightly shifted up, as compared to the partners' demand shifts. We also assume that the non-partner's post-alliance (inverse) demand shift may be expressed as

$$\rho_k^1 = d_k^1(Q_k^1, Q_k^2) + \alpha \xi, \quad 0 < \alpha < 1.$$

Then, it is straight forward to show that

$$\frac{\partial Q^1}{\partial \xi} = -[I - R_2^{1c} R_1^{2c}]^{-1} \left[(\Pi_{11}^{1c})^{-1} \Pi_{1\xi}^{1c} + R_2^{1c} (\Pi_{22}^{2c})^{-1} \Pi_{2\xi}^{2c} \right] \quad (43)$$

$$\frac{\partial Q^2}{\partial \xi} = -[I - R_1^{2c} R_2^{1c}]^{-1} \left[(\Pi_{22}^{2c})^{-1} \Pi_{2\xi}^{2c} + R_1^{2c} (\Pi_{11}^{1c})^{-1} \Pi_{1\xi}^{1c} \right] \quad (44)$$

where $\Pi_{1\xi}^{1c} = [\alpha, \alpha, \alpha]^T$. Notice that if $\Pi_{1\xi}^{1c}$ is a zero vector, then (43)-(44) reduce to (41)-(42), respectively. Notice that the sign of the second bracketed term of the right-hand side of (43)-(44) is indeterminate. If demand functions for both the partners and non-partner are simultaneously shifted up, the effects of the complementary alliance on each firm's output and total output are no longer clear.

However, if we assume that the partners and non-partner are symmetric and the partners can provide connecting service at the same quality as the non-partner's, then we have

Proposition 5-1. In case where demand functions for the partners and non-partner are simultaneously shifted up by the complementary alliance, both competitors can increase output under the symmetric and $\gamma = 0$ conditions.

Proof. Under the symmetric conditions, $R_j^{1c} = R_i^{1c} (= R^c)$ and $(\Pi_{11}^{1c})^{-1} = (\Pi_{22}^{2c})^{-1}$. Thus, (43)-(44) can be rewritten as

$$\frac{\partial Q^1}{\partial \xi} = -[I - (R^c)^2]^{-1} \left[(\Pi_{11}^{1c})^{-1} \Pi_{1\xi}^{1c} + R^c (\Pi_{11}^{1c})^{-1} \Pi_{2\xi}^{2c} \right] \quad (45)$$

$$\frac{\partial Q^2}{\partial \xi} = -[I - (R^c)^2]^{-1} \left[(\Pi_{11}^{1c})^{-1} \Pi_{2\xi}^{2c} + R^c (\Pi_{11}^{1c})^{-1} \Pi_{1\xi}^{1c} \right]. \quad (46)$$

According to the stability condition, the magnitude of the eigenvalues of matrix, $(R^c)^2$, must be less than one, and so does R^c . Thus, $\partial Q^2 / \partial \xi > 0$ since the second bracket term of (46) is negative. It is also possible that $\partial Q^1 / \partial \xi > 0$, depending on α . Q.E.D.

5.2 Parallel alliance

We will focus on the analysis of the "no shut-down" case here since the same results can be obtained for the "shut-down" case by the same analysis. Assuming that the partners' "full" price demand functions in AH market are shifted up, the partners' post-alliance (inverse) demand shifts may be written as

$$p_{AH}^i = d_{AH}^i(Q_{AH}^i, Q_{AH}^j) + \xi; \text{ for } i, j = 1, 2; i \neq j.$$

Denoting a "stable" equilibrium by $(Q^1(\theta, \xi), Q^2(\theta, \xi), Q^3(\theta, \xi))$, and differentiating the first-order conditions with respect to ξ , we have

$$\Pi_{11}^{1p} \frac{\partial Q^1}{\partial \xi} + \Pi_{12}^{1p} \frac{\partial Q^2}{\partial \xi} + \Pi_{13}^{1p} \frac{\partial Q^3}{\partial \xi} + \Pi_{1\xi}^{1p} = 0, \quad (47)$$

$$\Pi_{21}^{2p} \frac{\partial Q^1}{\partial \xi} + \Pi_{22}^{2p} \frac{\partial Q^2}{\partial \xi} + \Pi_{2\xi}^{2p} = 0, \quad (48)$$

$$\Pi_{31}^{3p} \frac{\partial Q^1}{\partial \xi} + \Pi_{33}^{3p} \frac{\partial Q^3}{\partial \xi} = 0 \quad (49)$$

where $\Pi_{1\xi}^{1p} = [1, 0, 0]^T$ and $\Pi_{2\xi}^{2p} = 1$.

From (49), it can be easily verified that $\partial Q^1/\partial \xi$ and $\partial Q^3/\partial \xi$ have opposite signs. Solving (47)-(48) for $\partial Q^1/\partial \xi$ and $\partial Q^2/\partial \xi$ yields

$$\frac{\partial Q^1}{\partial \xi} = -[I - R_3^{1p} R_1^{3p}]^{-1} (\Pi_{11}^{1p})^{-1} \left(\Pi_{1\xi}^{1p} + \Pi_{12}^{1p} \frac{\partial Q^2}{\partial \xi} \right), \quad (50)$$

or

$$\frac{\partial Q^2}{\partial \xi} = -(\Pi_{22}^{2p})^{-1} \left(\Pi_{2\xi}^{2p} + \Pi_{21}^{2p} \frac{\partial Q^1}{\partial \xi} \right). \quad (51)$$

Notice that the sign of the last term of (50)-(51) can be either positive or negative, depending on the difference between the positive direct effects of the demand shift on each partner's marginal profit (i.e., $\Pi_{1\xi}^{1p}$ and $\Pi_{2\xi}^{2p}$) and the negative indirect effects due to strategic substitutes condition (i.e., $\Pi_{12}^{1p} \cdot (\partial Q^2/\partial \xi)$ and $\Pi_{21}^{2p} \cdot (\partial Q^1/\partial \xi)$). If the direct effects simultaneously dominate the indirect effects in (50)-(51) (i.e., $|\Pi_{1\xi}^{1p}| > |\Pi_{12}^{1p} \cdot (\partial Q^2/\partial \xi)|$ and $|\Pi_{2\xi}^{2p}| > |\Pi_{21}^{2p} \cdot (\partial Q^1/\partial \xi)|$), then $\partial Q^1/\partial \xi > 0$ and $\partial Q^2/\partial \xi > 0$. Therefore,

Proposition 5-2. If the parallel alliance shifts both partners' demand functions upward and the direct effects of the demand shifts dominate the indirect effects, it is possible for both partners to simultaneously increase output in market AH. It is therefore possible that total output in market AH increases and thus consumer surplus increases.

6. EMPIRICAL TEST

This section carries on an empirical test for some propositions regarding the effects of the alliances on each firm's output and total output. Previous sections have shown that complementary and parallel alliances have different effects on each firm's output and total output. After the complementary alliance, the partners increase local traffic (see Propositions 3-1 and 5-1). The non-partner can increase (see Proposition 3-1) or decrease (see Proposition 5-1) local traffic, depending on the degree of demand shift. Consequently, total output increases in the local markets (see Proposition 3-3).

On the other hand, from the analysis of the parallel alliances, the partners are likely to

decrease local traffic on the AH segment under both the "no shut-down" and "shut-down" cases (see Propositions 4-1, 4-2, 4-4 and 5-1). Changes in the non-partners' outputs are uncertain under the "no shut-down" case, but the non-partner decreases local traffic on the BH segment under the "shut-down" case (see Propositions 4-4). Consequently, total output on the AH segment is likely to decrease in market AH (see Propositions 4-3 and 4-6).

In order to test those predictions, we selected seventeen trans-Atlantic routes where either complementary or parallel alliance occurred between US and European carriers. Since major alliances in the North Atlantic markets were formed in the early 1990's, annual data for two-ways of the seventeen routes (e.g., Atlanta to Amsterdam, and Amsterdam to Atlanta) were collected for the 1990-94 period. Observations were collected for alliance partners and their strongest competitor¹³ for each of the seventeen routes. The total numbers of observations available for the alliance partners and the largest non-aligned carriers are 151 and 97, respectively.

Data associated with strategic alliances were mainly taken from the *Official Airline Guides: Worldwide Edition*. To classify the data into pre-, post-complementary, and post-parallel alliance situations, we used a variety of data sources including *Airline Business* (1994), *Gellman Research Associates* (1994), and *U.S. General Accounting Office* (1995). Thirty-six observations were classified into the complementary alliance situation, while sixteen were categorized into the parallel alliance situation. Four cases were classified as a mixture of the two types (Lufthansa/United on Chicago-Frankfurt and Washington, D.C.-Frankfurt routes).

The aligned-partners' traffic, non-partners' traffic, and total traffic data on the seventeen routes were gathered from the International Civil Aviation Organization (ICAO) publication, *Traffic By Flight Stage*. The mean value for the aligned-partner's passenger volume during the period is 108,200 people, while the mean value for the total traffic is 247,770 people. The number of carriers on each route was also obtained from the ICAO publication.

The aligned-partners' traffic, non-partners' traffic, and total traffic, respectively, are treated as a dependent variable on each set of regression. As explanatory variables, presence of complementary alliance (CA), presence of parallel alliance (PA), the number of airlines on each route (NUM), year-specific characteristics (YR), and route-specific characteristics are considered. Route Atlanta-Amsterdam and year 1990 is used as a base route and year in the regression. For robustness of analysis, we test the hypotheses by using four different specifications for each set of regression.

Table 1 shows test results. The test results generally confirm the theoretical predictions. First, as shown in the first column of Table 1, the test result on alliance partners' outputs is consistent with the corresponding propositions. As expected, all coefficients of CA are estimated as positive, regardless of specifications. More importantly, the coefficients of CA are estimated as highly significant under the specifications (1) and (2). This result confirms

¹³ In order to control a firm size effect, we restrict our attention to the strongest non-aligned firm, the largest firm other than alliance partners on each of the alliance routes. Not every non-aligned firm on the route may react to the alliance. Presumably, small firms are not likely to do so.

that each of complementary alliance partners increases its traffic after the alliance. For parallel alliance partners' outputs, all coefficients are estimated as negative, implying that demand shift effects on the partners' outputs are weak. The coefficients of PA under the specifications (3) and (4) are estimated as negative and significant.

Second, the last column of Table 1 shows that test result on total output is highly consistent with the corresponding predictions. The coefficients of CA and PA are estimated as properly and significantly, regardless of specifications. Following the complementary alliance, total traffic increases by an average of 11-17 per cent of the average total traffic. In contrast, total traffic decreases by an average of 11-15 per cent of the average total traffic, due to the parallel alliance. Notice that total passenger volumes of years 1993 and 1994 are not significantly different from that of year 1990.

Third, the second column of Table 1 indicates that the test result on non-partners' outputs is partly consistent with the corresponding propositions. In general, the signs of the coefficients are consistent with the propositions, but statistically insignificant. In three out of the four specifications, the coefficients of CA are estimated as positive. As shown in the Extended Model, the complementary alliances in the North Atlantic markets may generate new demands, some of which cannot be served by the alliance partners and can be left over to non-aligned competitors. The signs of the coefficients of PA are consistent with the theory, although the coefficients are estimated as insignificant.

7. CONCLUDING REMARKS

This study analyzes the effects on market outcome and welfare of two types of alliances: complementary vs. parallel alliances. To recapitulate major findings of this study,

First, the complementary alliance in a specific market has indirect positive effects on the partners' outputs in the other markets. Coordination in connecting markets allows the partners to increase service quality and decrease average operating costs in local markets. This is because multiple products are serviced through the same network and thus the alliance in a specific market has indirect impacts on each firm's output in the other markets within the same network.

Second, the two types of alliances have different effects on total output and consumer surplus. Given the symmetry, the complementary alliance increases total output, and decreases "full" price. Thus, consumer surplus increases as a result of the complementary alliance. On the other hand, both the "no shut-down" and "shut-down" parallel alliances are likely to decrease total output on the alliance route. Consequently, consumer surplus is likely to decrease due to the parallel alliance.

Third, we find sufficient conditions under which complementary alliance improves total welfare. Total welfare can rise if the partners and non-partners are symmetric and if the partners can coordinate to the extent that they are able to provide the same level of connecting services as firm 1's.

Four, the Extended Model finds that demand shifts due to strategic alliances play a crucial role on changes in firms' outputs under certain conditions. For the complementary alliance case, it is possible for both alliance partners and non-partner to simultaneously increase their outputs in cases where there are some created demands being spilled over to the non-partner. The Extended Model identifies sufficient conditions under which parallel alliance partners simultaneously increase their outputs on the alliance route, resulting in increasing total output in the market.

Finally, the empirical test results generally confirm the theoretical predictions on alliance partners' outputs and total output. The test results indicate that the partners' traffic increases due to the complementary alliance, while the partners' traffic decreases due to the parallel alliance. The results also show that total traffic increases by an average of 11-17 per cent of the average total traffic due to the complementary alliance, while total traffic decreases by an average of 11-15 per cent of the average due to the parallel alliance.

These findings have some important policy implications. Government agents should be very careful to allow would-be parallel alliance partners to have antitrust immunity. Since the partners are significant competitors in the same markets, competition may be reduced if they are able to integrate operation with the protection of antitrust immunity. As a result, the parallel alliance reduces consumer surplus and is more likely to decrease total welfare. However, under certain conditions, allowing more complementary alliances may have the potential of creating a more competitive environment and improving welfare.

ACKNOWLEDGEMENTS

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FIGURE 1. A Simple Air Transport Network

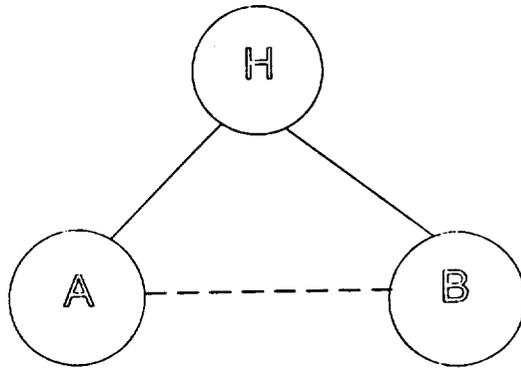


TABLE 1. Effects of alliances on partners' traffic, non-partners' traffic, and total traffic

	Passengers for partners				Passengers for non-partners				Total passengers			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
CA	20,174 c	21,397 c	5,300	7,496	1,189	1,965	-1,262	3,400	42,180 c	43,480 c	29,670 b	27,205 b
PA	-2,273	-6,800	-12,639 c	-13,895 b	3172	-536	-560	-1,836	-28,033 b	-32,843 b	-37,046 c	-35,636 b
NUNI		-6,793 c		-3,454		-5,579 c		-5,386 b		-7,216		3,876
YR91			-7,480 b	-4,425			1,503	7,065			-33,490 c	-36,919 c
YR92			10,318 c	11,168 c			15,380 c	16,478 c			5,340	4,386
YR93			10,044 c	10,229 b			17,284 c	18,563 c			1,395	1,186
YR94			22,822 c	21,860 c			13,071 m	10,328			9,521	10,601
ATL-BRU	-17,550 b	-12,778	-19,451 b	-16,741 b					-21,081	-16,012	-23,475	-26,516
ATL-FRA	-2,086	-2,086	-2,086	-2,086	43,418 c	43,418 c	43,418 c	43,418 c	41,332 b	41,332 b	41,332 c	41,332 c
BOS-AMS	13,646 b	6,609	16,621 c	12,728 a					-51,756 c	-59,232 c	-49,254 c	-44,885 c
BOS-LON	67,487 c	79,469 c	70,462 c	76,239 c	41,651 c	51,537 c	42,141 c	50,903 c	214,110 c	226,840 c	216,610 c	210,130 c
BWI-LON	-39,379 c	-43,754 c	-36,772 c	-39,242 c					-99,122 c	-103,770 c	-98,018 c	-95,246 c
CHI-FRA	29,034 c	36,732 c	31,107 c	34,812 c	-4,780	1,540	-4,034	1,607	78,597 c	86,776 c	80,400 c	76,242 c
DET-AMS	2,129	-5,153	2,511	-1,418					67,674 c	-75,411 c	-70,715 c	-66,306 c
LAX-LON	137,530 c	160,630 c	137,530 c	149,270 c	10,037 a	28,301 c	6413	24,059 c	375,050 c	399,590 c	375,050 c	361,870 c
MSP-AMS	25,398 c	21,023 b	28,005 c	25,535 c					-50,217 b	-54,866 b	-49,114 b	-46,342 c
NYC-AMS	127,220 c	144,890 c	127,220 c	136,200 c	8,238	21,069 c	8238	20,625 c	171,010 c	189,770 c	171,010 c	160,930 c
NYC-BRU	36,464 c	58,672 c	35,562 c	46,959 c					97,238 c	120,830 c	96,535 c	83,748 c
NYC-LON	392,920 c	421,450 c	392,920 c	407,430 c	-21,447 c	-3,256	-21,191 c	-3,307	111,530 c	114,560 c	111,530 c	109,900 c
NYC-ZRH	38,204 c	47,052 c	39,375 c	43,771 c					56,545 c	65,945 c	57,648 c	52,715 c
PHL-LON	24,382 c	25,496 c	27,357 c	27,608 c	-18,488 c	-11,271 a	-17,486 c	-10,657 a	-16,017	-14,834	-13,515	-13,797
VAS-AMS	-17,899 a	-18,266 b	-22,729 c	-22,374 c					-50,064 b	-50,454 b	-55,216 c	-55,614 c
VAS-FRA	14,669 b	23,725 c	16,742 c	21,137 c	-11,566 a	4,855	-15,792 b	9,442	81,836 c	91,458 c	83,639 c	78,706 c
CONST	47,131 c	60,471 c	42,965 c	48,807 c	60,763 c	71,765 c	51,806 c	60,606 c	103,730 c	117,900 c	109,680 c	103,120 c
R-squared	0.979	0.981	0.984	0.985	0.877	0.888	0.918	0.918	0.985	0.986	0.987	0.987

[Note] a: p-value<0.1, b: p-value<0.05, c: p-value<0.01

APPENDIX

This part provides the proofs of Propositions 4-4, 4-5, and 4-6. Each firm's pre-alliance profit function can be expressed as

$$\begin{aligned}\Pi^{1b} &= \sum_{k=AH}^{BH} Q_k^1 [d(Q_k^1, Q_k^1) - g(Q_k^1 + Q_{AB}^1)] + Q_{AB}^1 \left[d(Q_{AB}^1) - \sum_{k=AH}^{BH} g(Q_k^1 + Q_{AB}^1) \right] - \sum_{k=AH}^{BH} C(Q_k^1 + Q_{AB}^1), \\ \Pi^{2b} &= Q_{AH}^2 [d(Q_{AH}^2, Q_{AH}^2) - g(Q_{AH}^2)] - C(Q_{AH}^2), \quad \Pi^{3b} = Q_{BH}^3 [d(Q_{BH}^3, Q_{BH}^3) - g(Q_{BH}^3)] - C(Q_{BH}^3)\end{aligned}$$

where superscript b stands for before-alliance. Using specifications (37)-(38) and solving the first-order conditions, we have the following pre-alliance quantities

$$Q_{AH}^{1b} = Q_{BH}^{1b} = \frac{(\lambda^2 - 2\lambda + 2)\alpha - 4}{2(3\lambda^2 - 7\lambda + 3)} \quad (A1)$$

$$Q_{AB}^{1b} = \frac{(1 - \lambda)[(3 + \lambda)\alpha - 12]}{2(3\lambda^2 - 7\lambda + 3)} \quad (A2)$$

$$Q_{AH}^{2b} = Q_{BH}^{3b} = \frac{(2 - 5\lambda)\alpha - 4(1 - 3\lambda)}{2(3\lambda^2 - 7\lambda + 3)}. \quad (A3)$$

where $\lambda = 2\delta + \mu$. It can be shown that the second-order conditions for each firms' profit maximization problem reduce to $\lambda < 2/3$. Since outputs and marginal revenues (costs) should be positive, α is constrained such that $6/(\lambda + 3) < \alpha < [6(1 - \lambda)]/[\lambda(5 - 4\lambda)]$ for $0 < \lambda < 2/5$.

The shut-down parallel-alliance profits for the firms can be expressed as

$$\begin{aligned}\Pi^{(1+2)p} &= Q_{AH}^1 [d(Q_{AH}^1) - g(Q_{AH}^1 + Q_{AB}^1)] + Q_{BH}^1 [d(Q_{BH}^1, Q_{BH}^1) - g(Q_{BH}^1 + Q_{AB}^1)] + Q_{AB}^1 \left[d(Q_{AB}^1) - \sum_{k=AH}^{BH} g(Q_k^1 + Q_{AB}^1) \right] \\ &\quad - \sum_{k=AH}^{BH} C(Q_k^1 + Q_{AB}^1), \quad \Pi^{3p} = Q_{BH}^3 [d(Q_{BH}^3, Q_{BH}^3) - g(Q_{BH}^3)] - C(Q_{BH}^3)\end{aligned}$$

where superscript p stands for parallel alliance. Solving the first-order conditions for the shut-down parallel alliance yields the following parallel alliance solutions:

$$Q_{AH}^{(1+2)p} = \frac{(\lambda^3 - 5\lambda^2 + 11\lambda - 6)\alpha + 2(\lambda^2 - 8\lambda + 6)}{6\lambda^3 - 27\lambda^2 + 34\lambda - 12} \quad (A4)$$

$$Q_{BH}^{1p} = \frac{(\lambda^3 - 5\lambda^2 + 6\lambda - 4)\alpha + 2(\lambda^2 - 2\lambda + 4)}{6\lambda^3 - 27\lambda^2 + 34\lambda - 12} \quad (A5)$$

$$Q_{AB}^{1p} = \frac{(1-\lambda)[(\lambda^2-6)\alpha - 2(5\lambda-12)]}{6\lambda^3 - 27\lambda^2 + 34\lambda - 12} \quad (\text{A6})$$

$$Q_{BH}^{3p} = \frac{(2-\lambda)[(5\lambda-2)\alpha - 2(6\lambda-2)]}{6\lambda^3 - 27\lambda^2 + 34\lambda - 12}. \quad (\text{A7})$$

Again, it can be shown that the second-order conditions reduce to $\lambda < 2/3$. From the positive outputs and marginal revenues constraints, $\frac{6}{\lambda+3} < \alpha < \frac{2\lambda^0 - 16\lambda + 12}{\lambda(4\lambda^0 - 17\lambda + 12)}$ for $\lambda < \frac{2}{5}$.

Proof of Proposition 4-4. Using (A1)-(A6), we can calculate changes in the partners' output due to the shut-down parallel alliance:

$$\Delta Q_{AH}^{(1+2)p} = Q_{AH}^{(1+2)p} - [Q_{AH}^{1b} + Q_{AH}^{2b}] = - \frac{(\lambda-1)(5\lambda^2 - 14\lambda + 6)[(2-5\lambda)\alpha + 12\lambda - 4]}{(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)(3\lambda^2 - 7\lambda + 3)} \quad (\text{A8})$$

$$\Delta Q_{AB}^{1p} = Q_{AB}^{1p} - Q_{AB}^{1b} = - \frac{\lambda(1-\lambda)[(5\lambda^2 - 17\lambda + 6)\alpha - 2(6\lambda^2 - 20\lambda + 6)]}{2(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)(3\lambda^2 - 7\lambda + 3)} \quad (\text{A9})$$

$$\Delta Q_{BH}^{1p} = Q_{BH}^{1p} - Q_{BH}^{1b} = - \frac{\lambda^2(2-\lambda)[(2-5\lambda)\alpha + 2(6\lambda-2)]}{2(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)(3\lambda^2 - 7\lambda + 3)}. \quad (\text{A10})$$

Since the denominator of (A8)-(A10) is negative for $\lambda < 2/5$, the sign of these equations depends on the numerator. It can be shown that the numerator of (A8) is negative, while those of (A9) and (A10) are positive for the feasible α and λ . Similarly, we can calculate, using (A3) and (A7), changes in firm 3's output

$$\Delta Q_{BH}^{3p} = Q_{BH}^{3p} - Q_{BH}^{3b} = \frac{\lambda^2[(2-5\lambda)\alpha + 2(6\lambda-2)]}{2(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)(3\lambda^2 - 7\lambda + 3)}$$

which is negative for the feasible range.

Q.E.D.

Proof of Proposition 4-5. Using (A1)-(A7), we can compute changes in the partners' profit and changes in firm 3's profit

$$\Delta \Pi^{1p} = \Pi^{1p} - \Pi^{1b} = - \frac{I\alpha^2 + J\alpha + K}{4(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)^2(3\lambda^2 - 7\lambda + 3)^2} \quad (\text{A11})$$

$$\Delta \Pi^{2p} = \Pi^{2p} - \Pi^{2b} = \frac{L\alpha^2 + M\alpha + N}{8(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)^2(3\lambda^2 - 7\lambda + 3)^2} \quad (\text{A12})$$

$$\Delta \Pi^{3p} \equiv \Pi^{3p} - \Pi^{3b} = -\frac{\lambda^2(\lambda-2)(12\lambda^3-53\lambda^2+68\lambda-24)[(5\lambda-2)\alpha+2-6\lambda]}{8(6\lambda^3-27\lambda^2+34\lambda-12)^2(3\lambda^2-7\lambda+3)^2} \quad (\text{A13})$$

where $I=90\lambda^{10}-942\lambda^9+3949\lambda^8-8041\lambda^7+6312\lambda^6+5352\lambda^5-16539\lambda^4+15333\lambda^3-6794\lambda^2+1344\lambda-72$,
 $J=-2(144\lambda^9+1302\lambda^8+4768\lambda^7-8614\lambda^6+5640\lambda^5+7522\lambda^4-19480\lambda^3+17324\lambda^2-7176\lambda+1152)$,
 $K=-4(324\lambda^M-4302\lambda^A+23973\lambda^A-74128\lambda^E+141439\lambda^K-174420\lambda^I+140005\lambda^I-70648\lambda^0+20292\lambda-2520)$,
 $L=180\lambda^{0n}-1344\lambda^M+1592\lambda^A+14019\lambda^A-63462\lambda^E+120822\lambda^K-124872\lambda^I+71846\lambda^I-20996\lambda^0+2064\lambda+144$,
 $M=-2(2016\lambda^M-22620\lambda^A+104444\lambda^A-256128\lambda^E+357312\lambda^K-276612\lambda^I+96936\lambda^I+5912\lambda^0-14160\lambda+2880)$,
 $N=4(648\lambda^M-6300\lambda^A+22218\lambda^A-27160\lambda^E-30210\lambda^K+136392\lambda^I-180338\lambda^I+119176\lambda^0-39768\lambda+5328)$.
It can be numerically shown that (A11) is positive while (A13) is negative for the feasible α and λ . The sign of (A12) varies depending on value of α and λ . Q.E.D.

Proof of Proposition 4-6. From (A8), $\Delta P_{AH}^c > 0$. Thus, $\Delta CS_{AH}^c < 0$. Similarly, from (A9), $\Delta P_{AB}^c < 0$. Thus, $\Delta CS_{AB}^c > 0$. Using (A1), (A3), (A5), and (A7), we can calculate

$$\Delta P_{BH}^p \equiv P_{BH}^p - P_{BH}^b = \frac{\lambda^2(1-\lambda)[(2-5\lambda)\alpha+2(6\lambda-2)]}{2(6\lambda^3-27\lambda^2+34\lambda-12)(3\lambda^2-7\lambda+3)}$$

which is negative for the feasible range. Consequently, $\Delta Q_{BH}^c > 0$ and $\Delta CS_{BH}^c > 0$. Q.E.D.

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**STRATEGIC ALLIANCES AMONG INTERNATIONAL AIRLINES AND
THEIR IMPLICATIONS FOR ORGANISATIONAL CHANGE**

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1 INTRODUCTION

Globalisation has resulted in international trade progressing beyond the stage where national firms specialise in finished products. Specialisation now occurs in the production of components and the modern trading enterprise engages in global sourcing (Frank, 1995). Improvements in communications and transport have made this possible, but competition, rising customer expectations and the need to expand markets beyond national boundaries leave many businesses with no alternative but to "go global". Growth ambitions can be accommodated through merger and acquisitions, but the imperative to seek out the most efficient ways to serve markets is leading to new forms of organisation and relationships among organisation. Collaborative relationships have made it possible to serve a global market, to achieve economies in production, to employ the latest technology and to gain access to markets. As a result, the strategic alliance has been integral to the globalisation process in a diverse set of sectors ranging from clothing and footwear to aeronautics (Ohmae, 1989; Lorange *et al.*, 1992).

Against this background, researchers have paid increasing attention to the attempts in the airline industry to globalise (Gialloredo, 1988; Doganis, 1994). While it is true that the larger international carriers compete simultaneously in several inter-continental markets, restrictions on foreign investment and commercial operating rights generally deny airlines the opportunity to become global businesses in their own rights. Airlines do not have free access to markets, nor do they have the freedom to invest and operate wherever they want. The principles of comparative advantage do not prevail in the trade in airline services and consequently, airlines are prevented from developing efficient global networks. Alliances allow airlines to circumvent restrictions on market access while simultaneously permitting them to co-ordinate schedules and to pursue other practices designed to reduce costs and improve customer service. The strategic alliance has become the key instrument for global expansion.

The regulatory response so far has been relatively tolerant. The United States has had the clearest policy of accepting alliances that operate within competitive markets. When an alliance results in dominance of a market, the US approach has been to reduce any barriers to entry entrenched through route allocations and control over landing slots at hub airports. Other governments have tended to deal with individual cases on their own merits. Airlines have justified the alliances on the basis of better service and lower costs. However, the regulators and the industry they oversee both share concerns about where the alliances are leading and the ability of the regulatory system to respond to evolving conditions (Burton and Hanlon, 1994; Alamdari and Morrell, 1997). Furthermore, the problems are becoming increasingly complex as coalitions among key airlines fluctuate and as it becomes more and more difficult to define the relevant market for the purposes of analysing concentration. While airlines are developing network strategies, the regulatory framework tends to focus attention on point-to-point services.

The proposed alliance between American Airlines and British Airways has brought matters to a head in trans-Atlantic relations when the regulatory bodies in the United States, the United Kingdom and the European Commission each proposed different requirements. Australia has been reluctant to approve an extension of the code-share agreement between British Airways and Qantas Airways (Findlay *et al.*, 1997). Airlines are under increasing pressure to demonstrate that alliances are not anti-competitive and that they deliver long-term benefits to consumers. The initial focus of researchers was on the formation of alliances and their role in globalisation (Pustay, 1992; Burton and Hanlon, 1995; Park *et al.*, 1995). Code-sharing has been a key instrument used in airline alliances and there is considerable interest in the way this device is used in competition and its value to consumers (Humphreys, 1995; Hannegan and Mulvey, 1996). A particular theme is how alliances, especially code-sharing, have an impact on market shares and on the performance and strategic positioning of the carriers (Oum *et al.*, 1993; Park, 1997). Further contributions have examined the process of alliance formation and the conditions that favour success (Flanagan and Marcus 1993; Park and Cho, 1997).

A common theme is that strength and permanency are achieved through exchanges of equity (Tretheway, 1991). This results in the airlines becoming "mutual hostages" and minimises the risks of partners pursuing opportunistic actions. Merger and acquisition can be used to address these problems, but restrictions on foreign ownership in the international airline industry favour the strategic alliance. However, the role of equity has been overemphasised. We argue that this has diverted attention away from contributions in management theory that explain how contracts, constructs and property rights are being used to forge new types of relationships within

strategic alliances. It is common for partners to enter into a series of alliances and therefore, it is necessary to consider this organisational form in a dynamic setting (Gulati, 1995).

While we do not deny there is a strong basis for the presumption that alliances among international airlines are largely the result of regulatory conditions, we believe it is useful to explore the question "would alliances persist in competitive world markets?". On the basis of experiences in other forms of business and our understanding of the economics of airline operations we consider globalisation and alliance formation to be a natural condition in the airline sector. By investigating the likely form of alliances under competitive conditions we aim to shed insights into the benefits that alliances are capable of delivering. However, this raises fundamental questions about the nature of airlines as organisations and about the way they are likely to evolve in response to competitive pressures in the globalisation process.

2 GLOBALISATION, STRATEGIC ALLIANCES AND AIRLINES

Co-operative behaviour in the international airline industry has been evident ever since pioneering carriers began to develop their networks and airlines do compete simultaneously in several continental markets. However, this does not mean that airlines have been forming "strategic alliances" and "globalising" throughout their history. These terms have particular meanings in organisational theory, and we commence with an explicit discussion about these topics before considering their implications for contemporary behaviour in the airline industry.

In the post-war period, the General Agreement on Trade and Tariffs (GATT) promoted free trade by establishing a set of rules and principles that were non-discriminatory and it sought to minimise impediments to trade through government regulation. Nevertheless, the dominant model for a successful business was to develop a profitable domestic market and exporting played a relatively minor role. During the 1970s and 1980s, multinational corporations came to the fore, but the approach was to replicate production processes with strong control from the centre of the organisation. Often the multinational corporation invested abroad to take advantage of lower costs of production and output, especially in developing countries. The global enterprise represents a higher order of evolution in response to a set of environmental conditions.

The emergence of a large middle class, most notably in Asia, has expanded markets at the same time, increasing the power of the consumer. Markets tend now to be "pulled" by consumers rather than being "pushed" by suppliers. Barriers to competition have been reduced within and between economies so that businesses are under pressure to deliver better quality with higher levels of customer service at lower costs. Many businesses have found that their growth ambitions cannot be realised unless they expand out of their home markets, especially those firms that serve niche markets with highly specialised products and services. Harmonisation of product standards also has widened the scope for global competition. In some industries, the investment required to research and develop new products has escalated, and global expansion allows businesses to tap a wider pool of expertise as well as making it possible to spread the costs and risks.

Taking advantage of lower costs of production remains a powerful incentive to invest abroad, but the approach now is to source components and services from the most competitive suppliers. Developments in communication and information technology have made it possible to co-ordinate diverse activities more easily while delivering a greater amount of information to consumers. Under these conditions, intra-industry trade has boomed on a world-wide basis and even small to medium-sized enterprises have become important within global supply chains. The distinctive features of global businesses are in the ways they plan and organise sourcing and in the scope of their marketing.

Is it true then that the international airline industry is an example of globalisation? Deregulation of domestic travel markets has increased competitive pressures and in many economies has resulted in greater integration of domestic and international operations (Hooper, 1997). In the United States, at least, the major carriers have pursued growth abroad as it appeared the domestic market was approaching maturity during the early 1990s (Pilariski and Thomas, 1995). Information technology, especially in the form of computer reservation systems, has made it possible to expand the scope of distribution systems and to compete effectively in more distant markets. Competitive strategies built upon hub-and-spoke operations, frequent flyer programs, and code-sharing have

increased the marketing strengths of the large carriers. As travel markets have expanded with rising incomes, destinations have come into direct competition with each other. Some of the traditional destination regions also have become important sources of travellers. There has been a convergence of "domestic " and "international" tourism markets and most of the world's largest airlines in the 1990s have developed complementary domestic and international networks as well as distribution systems.

All of these factors suggest that the "globalisation" is a *natural* state for the airlines. It also is true that increasing competition has forced airlines to reduce their costs. In some notable cases, airlines have responded to this by adopting global sourcing practices. Cathay Pacific, for example, was reported to have saved US\$25 million a year when it began employing its air crews from bases in the USA, UK and Australia in 1996 (Hewitt, 1996), having already located its data processing in Australia. Lufthansa has suffered from high labour costs in Germany and was considering how an alliance with a US carrier would allow it to reduce overheads by sourcing in North America (McMullan, 1992a). BA Engineering and Lufthansa Technik specialise in performing overhaul operations for other airlines. Atlas Air is another to take advantage of outsourcing initiatives by developing a strength in air cargo operations.

However, airlines are not free to mobilise their skilled workforces on a world-wide basis due to varying industrial legislation and restrictions on "doing business". There are limits on how much aircraft maintenance, catering, refuelling, administration and training can be provided by suppliers in other economies. Problems associated with co-ordinating crew rostering led to Cathay Pacific abandoning its attempt to establish a crew base in Bangkok for short-haul routes in 1997 (Ballantyne, 1997). The opportunities to reduce costs and improve customer service lie mostly in network development and the optimal use of aircraft within those networks.

In situations where airline markets have been deregulated, carriers have used mergers and acquisitions to rationalise networks and to pursue growth and diversification strategies. The primary motivation for a merger is to increase the combined wealth of the enterprises involved, increase the wealth of shareholders and create opportunities for improved operations. Mergers are highly visible and represent lumpy investment decisions in which the buyers and sellers consider they will be better off because of the synergies between the two organisations and the efficiencies that can be achieved under a single management. Competitive strength increases through combined marketing, production and distribution in addition to improved financial economies in the form of lower transaction costs and better coverage by financial analysts and media. The merged entity is able to eliminate excess capacity and perhaps is able to exert increased market power.

However, strategic alliances can be used to pursue these benefits and they can give competitors a low-cost route to gain new technology and access to markets. High fixed costs can be shared and complementary resources can be brought together. The sharing of technology and information can be linked to long-term commitments that require complex integration and large capital costs. The joint venture is one option for managing this integration, but strategic alliances rely on a more co-operative arrangement. Given that many strategic alliances involve equity swaps to reduce risks of dissolution and opportunistic behaviour, it is necessary to be clear about what distinguishes an alliance from a merger or joint venture.

Definitions about what constitutes a "strategic alliance" abound in the literature, but there are two essential characteristics that need to be considered. Firstly, the emphasis on "strategy"; one business chooses to cooperate to a greater or lesser extent with another in order to pursue its corporate objectives and/or in response to opportunities/threats arising in the external environment. Secondly, businesses become "allies"; each partner maintaining a separate identity with scope for independent action and dissolution. Mergers and acquisitions definitely are not strategic alliances and this is further elaborated below. Joint ventures and equity swaps have many of the necessary characteristics of alliances, but they are difficult to classify. The scope of the strategic alliance includes arrangements to pool resources, to ally and link systems, businesses become better "PALs" through strategic alliances (Kanter, 1989). In summary, strategic alliances are characterised by:

- a coalition of two or more organisations in an on-going relationship, but each is free to exit the relationship
- specific goals/objectives
- the pursuit of mutual, though not necessarily equal, benefits

- sharing resources or, at least, integrating resources to improve performance
- sharing risks and rewards and decision making
- covering only part of the activities of each partner so that each maintains a separate identity, with some functions not included in the agreement
- systems that are difficult to break down into constituent elements
- a concern for long-term issues facing members to develop and maintain a sustainable competitive advantage

Strategies are relevant only when there is the potential to create a degree of market power. In a highly competitive situation the enterprise has no option but to seek minimum costs and accept market prices. The adoption of a strategy suggests there is a choice and that the alliance will have scope to influence the market. However, the issues of control and scope for independent action raise fundamental questions about the nature of organisational forms emerging in response to globalisation. We will pursue these below, but first draw attention to some characteristics of airlines that make them candidates for alliance formation.

3 POTENTIAL OF AIRLINES AS CANDIDATES FOR STRATEGIC ALLIANCE

First and foremost, the airlines have a history of co-operative behaviour. For example, in 1933 Qantas, then a small regional airline, entered into a joint venture with Imperial Airways to win a contract to carry mail from Singapore to Australia (Findlay 1995). The result was Qantas Empire Airways, and the alliance partners were able to counter the development of a rival service proposed by KLM. As the international airline industry grew, collaboration played a vital role in fostering markets, in improving the economic positions of the carriers and in developing and transferring technical skills as carriers shared technical knowledge, performed maintenance on each other's aircraft, and co-operated in training. It is common for one airline to carry out ground handling and passenger processing on behalf of others. Also, airlines sell interline tickets as well as pooling revenue on routes and co-ordinating flight scheduling.

However, with advanced technology collaborative behaviour now code-sharing, block-booking arrangements, common computer reservations systems (CRS), joint frequent flyer plans, and equity swaps. These practices have been interpreted as manifestations of strategic alliances in the formation of global airlines (Gialloredo, 1988; Tretheway, 1991). The rush to forge alliances in Europe and the United States in late 1992 led one analyst to question whether they were simply a product of financial stress in the airline industry and panic about "being left isolated" (McMullen, 1992b). Others have observed that the process of alliance formation has had the characteristics of an "epidemic" with serious doubts about the claim that they are "strategic" (Alamdari and Morrell, 1997). The distinction between marketing alliances and genuine strategic alliances is an important one. Clearly, co-operative behaviour is pervasive in the airline business but it is questionable that many of the current alliances would prosper in liberal aviation markets.

Deregulation of the domestic airline industry in the United States provided hard evidence that hub-and-spoke networks allow carriers to improve productivity while increasing the effectiveness of marketing. The strategy of consolidating traffic at hubs requires that some routes be considered as the line haul and others serve a feeder role, and this hierarchy is evident in domestic markets through the distinction between major and regional airlines. Profits in the airline industry are highly leveraged around the break-even load factor and connecting traffic is important for survival at all levels of the airline industry. As a result, many of the most important competitive battles are fought in creating "seamless" travel for connecting passengers, for example, by co-ordinating schedules and transferring baggage. The customer is sold a single ticket with the designation of the major carrier (code-sharing) and the entire journey accrues frequent flyer points with the major carrier.

Vertical integration has its attractions and there are many cases where the major airline has acquired the feeder airlines, but it is possible to achieve a great deal within broad marketing alliances (Lovin 1986; Oster and Pickrell, 1987). Despite the need to integrate regional and major carriers' operations and marketing, there are important differences in terms of the density of markets, sector distances and the size of aircraft. Cost structures and organisational cultures can differ markedly and even when the major carrier has acquired the regional airline,

separate identities are maintained. The regional airline improves its marketing strength through the association with the major carrier, but it still needs to maintain its local identity. It is important in these arrangements to allow the smaller partner the flexibility to manage in a way that is appropriate to its circumstances and not be swamped by the policies adopted by the management of the larger carrier.

These lessons from domestic deregulation have implications at the international level, but there are some differences to consider. The broadening and increasing integration of domestic and international travel markets results in similar hierarchies of feeder and trunk carriers, although it is not clear that this will be expressed to the same extent in dominant hubs. Some of the major hubs are congested and there are constraints that prevent expansion of capacity. Also, high frequencies are not as important in long-distance travel and there is a greater incentive to open direct routes versus consolidating traffic through hubs. Ethnocentric behaviour is strong in the travel market and international airlines are very reluctant to abandon their national identities. More significantly, the cultural differences that would need to be accommodated within the one organisation pose a major challenge for the global airline.

In the absence of any restrictions on foreign investment in the airline sector, it is likely that mergers and acquisitions would occur and that networks with feeder and trunk services would develop to some degree. However, mergers and acquisitions would encounter major problems in terms of strategic and cultural fit as they attempt to mesh incompatible strategies, values and leadership styles. Alliances offer advantages in this context. Globalising airlines can use alliances to gain access to markets with less commitment of resources and a means to accommodate these problems. Strategic alliances go further than co-operation to link services. Through organisational change, strategic alliances make it possible to reap the full benefits of globalisation. The global alliance makes it possible to customise products to the needs of national markets while simultaneously, optimising operations and sourcing.

It follows from the review above that the overriding motive for the formation of strategic alliances is the urgency to manage a persistently, changeable environment (Quinn, 1992). With this in mind, the uncertainty regarding the future of an alliance is ever-present. It can be concluded from the review above that airline alliances are 'hollow' networks with little genuine organisational integration amongst members. The key defining feature of the strategic alliance is the degree of integration required to share decision making and resources as well as the willingness to pursue long-term competitive advantage. On this basis, we first examine this latest concept of organisation, most importantly focusing on the nature of the relationship between partners and conclude with a set of propositions associated with the development of strategic alliances.

4 STRATEGIC ALLIANCE AS NEW CONCEPT OF ORGANISATION

4.1 Intelligent enterprises

As previously stated, strategic alliances primarily are an aggregation of autonomous organisations that essentially retain their own identity and governance. The purpose of forming strategic alliances focuses on commercial objectives, strategic vision and leadership and ways of gaining a competitive advantage in volatile markets. More specifically, strategic alliances seek to acquire a form of organisational flexibility to adjust to change, to develop the organisational capacity (skills and resources) to develop successful products and services and to achieve operating economies and efficiencies (Powell, 1987).

In understanding this new concept of organisation, Quinn (1992) referred to strategic alliances as 'intelligent enterprises' that comprise complex, global information and decision support systems superseding many of the control and operational functions of their conventional counterparts. These issues in turn lead to a new concept of organising in terms of recreating a 'flatter' hierarchy with a membership-orientated culture concentrating on shared values, new learning and knowledge, and integration (Webster, 1992). The manner in which this is achieved varies from one organisational context to another (Ring and Van de Ven, 1992) and will be elaborated on below.

Transformational leadership is an important aspect in forming strategic alliances and managing change within them. The pressure to align enterprises brought about by new market structures and the extension of market boundaries beyond national ones is redefining the future organisational form in the airline industry. There is increased pressure for enterprise leaders to understand the organisational prerequisites for successful alliances such as a well-developed infrastructure of culture, process of organisational learning and rewarding ways to achieve integration amongst alliance partners.

4.2 Membership culture

In a strategic alliance, each enterprise represents a culture that has a varying degree of influence over its members' beliefs and behaviour. Enterprises '...like persons, have values and these values are integrated into some coherent value system.. in any [enterprise], the members generally have a set of beliefs about what is appropriate and inappropriate organisational behaviour' (Goodstein, 1983, pp. 203-4). In the same way that personality is not a direct explanation for a person's actions, enterprise culture is only one factor contributing to the performance of an alliance. Culture is related to the concept of 'strategic fit' as well as to the question as to the extent of similarity and diversity that exists between potential enterprise members in a strategic alliance. One assumption is the greater the similarity between the value systems of potential members, the more likely they will find accord. Enterprises whose cultures are more similar to than different from each other will develop alliances more timely and successfully (Harrison, 1972; Malekzadeh, 1988), and have greater financial success (Porter, 1985).

4.3 New learning and knowledge

An important aspect of developing membership culture is the process of organisational learning that alliance members engage in jointly and separately (Arygris, 1977). Increasing competitive pressures are fuelling concern over the extent to which alliances can 'learn' jointly. One perspective is that strategic alliances are less likely to foster learning when exposed to competition, instead leveraging their market position to obtain competitive advantage (Barnett and Burgelman, 1996). The fundamental dilemma for any strategic alliance is how to maintain its enterprise identity while simultaneously developing the alliance. Alliance development generally calls for substantial shifts in maintenance strategies to effect the active support and contribution of alliance members.

Strategic alliances require that members convey their learning to one another, develop shared understandings and externalise what they have learnt (Lyles and Schwenk, 1992). Organisational learning occurs when the actions of one party, in this case an enterprise member, contests the values of another and there is pressure to replace 'their' ideas with 'different' ones. A high level of cultural synergy may inhibit organisational learning where enterprise members 'think' in a similar way. In other words, too much similarity may constrain the potential benefits of the alliance because too little in terms of added-value and innovation is being contributed by enterprise members to the alliance. Others have argued, for example Parkhe (1991) that inter-firm cultural and organisational diversity adversely affects performance. However there is another perspective, cultural synergy may not equal cultural similarity. Two dissimilar cultures may reach synergy through the process of 'double-loop' learning (Arygris, 1977).

Members do not agree upon clear boundaries, cannot identify shared solutions and do not reconcile beliefs and multiple identities. Yet, these members contend they belong to a culture. They share a common orientation and overarching purpose, face similar problems, and comparable experiences. However, these shared orientations and purposes accommodate different beliefs and incommensurable technologies, these problems imply different solutions, and these experiences have multiple meanings... Thus, for at least some cultures to dismiss the ambiguities in favour of what is clear and shared is to exclude some of the most central aspects of members' cultural experience and to ignore the essence of their cultural community. (Meyerson et al., 1991, pp131-2)

In other words, learning jointly allows 'culture' to be 'unbundled' into its important components in a way that might not occur within a single enterprise. Yet, learning is often a slow process simply because, as enterprises are currently structured, they retard the transferring of information, ideas and expertise amongst partners. Organisational learning is instrumental to collective efficacy defined as the belief of enterprise members about whether they can perform successfully or not within a strategic alliance (Bandura, 1977). Alliances that have a low sense of efficacy are more inclined to respond negatively to organisational change than those with high efficacy (Beehr and Newman, 1978). How is high efficacy achieved?

Consensus-building with interactions amongst members plays a significant part in developing collective efficacy. Strategic alliances provide 'blurred boundaries' for learning to occur. The process of developing collective efficacy in alliances is assisted by 'skilled organisers' who span the enterprise boundaries of each member and transfer learning (Brown and Hosking, 1986). Innovations by one member need to translate into alliance-wide innovation. The alliance needs to be structured in a way that facilitates the emergence and action of these types of liaison roles for organisational success.

5 ORGANISATIONAL PREREQUISITES FOR SUCCESSFUL ALLIANCES

5.1 Organisational performance and organisational outcomes

In practice, alliances have had a high failure rate and this has been no less the case in the airline business (Flanagan and Marcus, 1993). This has led to a focus on the factors that contributed to the formation of the alliance, but these may have little do a failed outcome. Success of a strategic alliance is predicated on organisational performance (OP) and organisational outcomes (OC). OP is a function of actions congruent to organisational goals. Action takes the form of establishing a shared vision, communicating clearly, building inter-member trust, collaborating and sharing knowledge and decision making. These processes grounded in an impelling business strategy are essential from the outset of alliance formation (Kanter, 1994).

Performing successfully in a strategic alliance not only involves capability but also choices, for example, the choice to expend effort and to what degree as well as the choice to commit resources including knowledge and trust. Organisational outcomes include the degree to which enterprise members have met the goals and the extent to which they are satisfied with the strategic alliance. If one of the members perceives the alliance to be unfair the choice about their potential investment will be modified. The relationship between OP and OC is best understood in terms of the concept of organisational integration.

A strategic alliance rests on the premise that each member brings unique commitments to the alliance, requiring a process of integration. To integrate member commitments, each constituency in the alliance needs to understand and share in a collective mission. Success has to be grounded in the integration of human resources which leads to a greater probability of strategic and operational attainment. However, if the interrelationship between the partners is based largely on self-interest, competition and overt conflict, the members' attachment to the alliance is loose. Conversely, when the relationship between the constituencies is collaborative, partners become engaged in an alliance characterised by collective interest and equality. One of the difficulties in integrating the separate goals of various members in an alliance is the fundamental conflict over their individual control of scarce resources. Sources of conflict include information (technical expertise, quality); capital, physical resources, time (to learn) and intangible assets (industry reputation (Barney, 1986; Hill, 1990)). The relative control of these resources is reflected in each transaction within the alliance. Conflict over resources also mirrors the degree of trust amongst members.

5.2 Alliances based on exchange

To explain this point in more detail, a relationship of exchange is compared to that based on integration. Strategic alliances are firmly established on a relationship of exchange highlighting the interdependence between the enterprise members. An alliance based on 'exchange' is founded on a reciprocal relationship, with the members' contributions each linked to the other based on fair exchange of contributions, and outcomes proportional to investment. Trust is also an important part of an exchange relationship in terms the extent to which each member believes that the other(s) will meet their commitments to the alliance. Exchange sets up a competitive context, the nature of which is characterised by each member in the alliance declaring 'If I give you something, I want something in return'. The outcome subsequently leads to 'winners' and 'losers', depending on which member is best able to maximise their control over scarce resources. 'Losers' are more likely to resort to threat as a form of reprisal. Strong competition and fear of reprisal can be minimised through structuring the alliance along equitable lines. This is achieved by, for example, ensuring that each party has equal access to resources and opportunity to control them. In an alliance based on exchange, there is an element of uncertainty that is reduced with each transaction. Under these conditions, the culture of the alliance is at best 'co-operative' but remains a 'hollow' network as we witness amongst carriers at present.

5.3 Alliances based on integration

Alliances that go beyond exchange and strive for an integration of interests, goals, resources and values take on a different 'rationality' from those based purely on self-interest. A number of researchers (Johanson and Mattson, 1988; Malekzadeh, 1988) have stressed the significance of integration as an ideal process for strategic alliances. Consultants Booz, Allen & Hamilton (1985) reported that cultural integration was the most important factor, ahead of financial and strategic factors, in the success of acquisitions.

A strategy of integration establishes common interests amongst members through a process of ongoing negotiation. With the understanding that not all alliances are founded totally on conflict or calculative action, integration is the approach most likely to lead to the initiation, development and maintenance of a strategic alliance. An integrative strategy therefore encourages a 'negotiated order' within the alliance (Strauss, 1978). Negotiation is aimed at the maximisation of equitable outcomes for all members. Negotiation allows each constituency not only to preserve a cohesive social relationship but also to dissent without fear of reprisal about contribution and outcomes in the alliance. Members experience a sense of working towards a 'commonality' characterised by 'what is good for us is good for the alliance'. Integration is associated with enhanced efficacy and ultimately organisational capacity of the alliance. Strategic alliances based on integration are genuinely adding-value for customers and shareholders.

Walter (1985) found culture is a significant factor in the performance of hybrid organisations. A strategy of integration involves a major 'jelling' of distinct cultures, workforces and orientations. Integration requires a collective orientation to strategic purpose implying a mutual understanding and acceptance of the goals and strategies by various members. An integrative strategy addresses four main factors that affect the performance outcomes of alliances: breadth of purpose, boundary determination, value creation process and stability mechanisms (Borys & Jemison 1989). The purpose of the alliance is dynamic and varies over time as markets fluctuate, technologies change, legislation is modified and work structures are redesigned.

So what do successful strategic alliances require? If the means to the end have changed (as evidenced by alliances, mergers and acquisitions), new strategies are called for, requiring a renewed 'responsiveness' from enterprise members who are located either at the 'centre' or its boundaries. Strategic alliances often mean that people essentially have 'divided' loyalties and ambiguous commitment. Alliances will be less 'hollow' and successful when:

- new ways of thinking and doing emerge, and blockages are 'unfrozen'
- underlying conflicts are identified and addressed
- there is an emphasis on the interactive processes among people
- people engage in genuine problem solving
- tensions between dominant and weak logics and between old and new ones are overcome
- stakeholders who possess the most appropriate organisational knowledge are identified
- it is predetermined under what conditions it is appropriate for the dominant member to possess information without sharing it
- psychological contracts support and reinforce innovative behaviour

6 AIRLINE ALLIANCES IN A COMPETITIVE, GLOBAL MARKET

In a recent survey by *Airline Business*, it was revealed that there are more than 360 alliances among international carriers (Gallacher, 1997). Few of these display any strong commitment to organisational integration and it is more appropriate to regard them as competitive actions to pursue relatively short-term objectives. We consider them to be "hollow organisations rather than genuine attempts to develop new organisational relationships as part of a globalisation strategy. In the long-term, coalitions would continue to be formed, but specific memberships would vary depending upon the set of competitive conditions at any time. There can be no doubt that the existence of regulatory barriers to entering markets and to investment favour alliance formation. In the absence of the regulations, it is probable that genuine strategic alliances would continue to develop as an alternative to strategies based on mergers and acquisitions. We believe the key reason for this is that globalisation in the airline industry requires a network of services operating in regions with widely differing cultural conditions. Attempts to co-ordinate actions through merger and acquisitions will be confronted with problems of cultural fit and they will need to tailor services to local demands. Strategic alliances, though, are markedly different than simpler marketing and operational alliances. Alliances allow greater flexibility and added-value. More important, the model for success addresses the fundamental issues directly.

The benefits from these strategic alliances potentially accrue in improved performance and responses to consumer needs. The formation of strategic alliances allows carriers to question more actively, to overturn existing logics and to intervene more effectively in change. Strategic alliances force each enterprise address the nature of their contribution to hybrid organisation by identifying their core competency, expertise, resources and where they will add value. Strategic alliances present challenges to the airline industry that are not entirely novel, but they need to be reconsidered as a potential solution to many of the difficult questions facing it such as out and in-sourcing, downsizing and business failure.

Implicit in the pursuit of competitive advantage is the assumption that there is scope for market power. Business strategies seek to establish and defend positions in the market. The fundamental question for regulators is whether competition in the airline industry is a sufficiently strong enough force to produce outcomes that are "better" than what can be achieved under regulated conditions. The issues of concentration of market power, whether it be through mergers and acquisitions or through alliances, still need to be confronted. However, the organisational structures that emerge in strategic alliances are more complex and it will become progressively more difficult for individual governments to influence their behaviour. Moreover, regulators need to consider how their actions affect the development of genuine strategic alliances that have the potential to deliver long-term benefits.

7 CONCLUDING COMMENTS

We believe it is inappropriate to label most of the arrangements among the world's airlines as "strategic alliances" formed as part of a "globalisation process". It is better to regard them as competitive responses to current conditions, that is 'hollow' networks based on a relationship of exchange and not integration. To a large extent, the alliances are a by-product of the regulatory system. The key questions from a regulatory perspective are whether increasing concentration of market power is likely to occur in liberal market conditions and how this would have an impact on performance.

The current set of regulations restrict access to markets and prevent airlines from investing in each other. We believe that the regulations also inhibit the development of genuine strategic alliances because they impose issues of national sovereignty on a process where genuine integration that is, co-operation and a commitment to decision and resource-sharing is required.

We have argued that alliances would survive in liberal market conditions but they will be a more complex organisational form with a stronger commitment to the exploitation of the benefits of globalisation than dominant firms that see global expansion as simple extensions of their networks.

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Aviation Safety and the Increase in Inter-Airline Operating Agreements

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Abstract

Aviation is becoming increasingly internationalized not only because international traffic is itself growing rapidly but also because airlines are themselves beginning to lose their national identity as cross-equity holdings expand and as airline alliances grow in number. These changes affect the commercial and the regulatory environment in which aviation services are provided but they also have potential implications for air transport safety. Although air transport safety is often treated as part of public policy, it is also influenced by the commercial interests of the airlines themselves. While there has been a recognition of the need for a public policy response to the new world of globalization and strategic alliances that are now part of the air transport market, this policy response needs to be made in the context of changing private incentives affecting airlines' own attitudes to safety. This paper focuses on the changes in private incentives that the growth in airline alliances in particular may have on safety.

Introduction

The number of major aircraft accidents in 1996, combined with concerns expressed by the aircraft manufacturer Boeing, that, while in statistical terms civil aviation may be slowly getting safer or, at worst, no more dangerous, the sheer growth of aircraft movements in future years will result in a rise in the absolute number of accidents, has brought forth a response from the aviation sector (*THE ECONOMIST*, 1997). In the US, for instance, there has been the White House Commission on Aviation Safety and Security.

This has also happened at a time when the air transport market is experiencing considerable change. As with many other sectors, air transport service suppliers are responding to commercial pressures for increased internationalization to reap benefits on both the cost and demand sides. The growth of international airline alliances is the most transparent manifestation of this although there has been an even more rapid growth in point specific alliances. Alliances are seen by carriers as a means of exploiting economies of scale, density and scope in the provision of services and as a means to exploit economies of market presence in terms of patronage.

The growth in number and the nature of modern alliances have raised a series of policy issues concerned mainly with anti-trust issues. The concern of this paper is to look at another aspect of the globalization of the airline industry and of the growth of various forms of airline alliances and that is the potential effect of these developments on airline safety. In particular, it looks at the way market forces change and can influence the commercial incentive for airline operators to offer safe services. Public policy regarding safety has been reacting to changing conditions in aviation markets but such reaction should be in the context of the new commercial environment in which airlines provide their services.

The paper initially outlines some of the broad trends in globalization that are influencing and being influenced by developments in commercial aviation. It then turns to look at exactly what is taking place regarding airline alliances, and particularly those of a strategic nature. An important point here is that conceptually the details of any airline alliance may have specific safety implications. A model of how airline safety is incorporated in both corporate and public policy is then developed and subsequently the implications of strategic alliances are set within this context. The discussion is entirely concerned with aviation markets in what might be termed the industrial world. Strategic airline alliances do exist in many parts of the world but here we content ourselves with considering those involving partnerships between carriers based in the major, economically developed countries. The arguments may be somewhat different for other parts of the world.

Globalization and aviation

Globalization and internationalization are two of the major industrial trends of the late twentieth century (THURLOW, 1996). Part of these trends are reflected in the significant growth of trade that has taken place in the 1990s with real export growth in the industrialized countries that make up the Organisation for Economic Cooperation and Development (OECD) running at over 7% per annum. Put another way, from 1964 to 1992, first world production was up by 9%, but exports were up by 12%, and cross-border lending was up 23%. Equally, there has been a significant rise in foreign ownership of assets that are now estimated to total about \$1.7 trillion.

Whether these trends are passing fads or represent genuine long term adjustments to the way that production and trade is conducted it is perhaps premature to judge. The preliminary indications are, though, that they are more than transient trends.

This has also been taking place at a time when the institutional structure in which air transport services are provided has seen significant developments. The US deregulation of its domestic markets for air freight from 1977 and for passengers from 1978, combined with its subsequent commitment to an 'Open Skies' approach to international aviation the following year, have been instrumental in changing the way not only US policy is conducted but also, through both demonstration effects and direct knock-on effects, the ways in which many other air transport markets are now regulated (BUTTON, 1990; BUTTON and SWANN, 1989).

The intra-European market, in particular, is moving rapidly towards a situation akin to that found within the United States. Many European countries have unilaterally liberalized their own domestic markets while the European Union (EU)¹ has since 1988 through a succession of 'packages' moved to a position that by the middle of 1997 will leave air transport within the Union largely free from economic regulation (BUTTON, 1996a). These measures initially opened up regulated fare and capacity bands within the EU, but then went on to limit fare and entry controls only to instances where governments at both ends of a route agreed to them. The creation of a Single European Market from 1993 means that international air transport within Europe is essentially deregulated with full cabotage within member states being allowed from 1997 (BUTTON and SWANN, 1992).

¹ The title European Union (EU) is a comparatively new one and terms such as European Community or European Communities preceded it. For simplicity of exposition, however, it will be used throughout this paper. Currently the EU consists of Austria, Belgium, Denmark, France, Finland, Germany, Great Britain, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden. Other states such as Norway and Switzerland do have important agreements with the EU, for instance, regarding aviation, that tie them to the latter's overall policy.

Intra-European market liberalization has also been accompanied by liberalization of many bilateral agreements involving European states and the USA. The first such agreement involved the Netherlands and the US in 1992 but since that time a significant number of smaller European countries have made similar liberal agreements with the US and in 1996 a major Opens Sky agreement was also reached with Germany.

Outside of Europe and North America, the majority of national markets in South America have been liberalized with extensive privatization programs of different types. The markets in Australia and New Zealand have also been deregulated. Additionally, the establishment of the World Trade Organization has also brought into play, albeit in an extremely small role, a new and geographically wider policy making institution to supplement the roles already played by bodies such as the International Civil Aviation Organization and the International Air Transport Association (IATA). Aviation issues are also on the agenda of new regional groupings such as the Asian-Pacific Economic Council. There is continued pressure, therefore, for this international liberalization process to continue (ORGANISATION FOR ECONOMIC COOPERATION AND DEVELOPMENT, 1997)

This combination of market trends and institutional reforms, combined with rising incomes and increased leisure time, have contributed to the steady growth in demand that has taken place in aviation markets. Additionally, technology advances have meant that aircraft efficiency has risen and air traffic control systems, despite their continued inadequacies, can handle greater volumes of traffic. This has exerted positive effects on the cost side of the international air transport equation.

As a result of these trends, since 1960 air passenger traffic has grown world wide at an average rate of 9% a year and freight and mail traffic by some 11.0% and 7.0% respectively. This means that in 1995, for example, some 1.3 billion passengers were carried by the world's airlines. Civil aviation is, therefore, a major service industry contributing to both domestic and international transport systems. It facilitates wider business communications and has been a key component in the growth of tourism that is now one of the world's major employment sectors. In addition to passenger transport, aviation is also an important form of freight transport and some estimates suggest that it carries up to 60% of world trade by value.

Further, all the indications are that as a sector it will continue to expand into the foreseeable future albeit at differential rates in various geographical sub-markets. While forecasting of aviation markets, as with many other activities remains an art rather than a science, it seems likely that passenger traffic will grow at a rate of between 5.0% and 7.0% into the foreseeable future with much of this growth in the Asian-Pacific region (up to 9.0% a year). The forecasts are also for slower growth in the more mature US-European markets where North Atlantic traffic grew at an annual rate of 8% between 1982 and 1992 and by 5.0% for mid Atlantic routes over the same period. Nevertheless, the absolute size of the trans-Atlantic traffic flows, some 38.0 million passengers (about 13.9% of the world aviation market) in 1992, makes it quantitatively a very important aviation market. Further, taken together, the intra-European, US domestic and trans-Atlantic markets currently account for some 60% of world air traffic.

Strategic airline alliances

In line with many other sectors, aviation has experienced significant moves towards globalization and internationalization in terms of its market structure. Indeed, it is the stated objective of the major UK carrier, British Airways that it intends to become a 'global carrier'. In pursuit of wider market coverage, and in an effort to enhance their own internal

efficiency, airlines have followed a number of courses. The recent development of various forms of airline alliances is perhaps currently the most controversial of these (BUTTON, 1997).

The exact definition of what constitutes an airline alliance is a vague one especially given that the institutional arrangements linking airline activities is continually changing. The notion of airline alliances is, however, one that has recently come under public scrutiny in the wake of several much publicized efforts by number of major international airlines to link their operations. The nature of the ties differ between groupings and so has the success of airline partners in gaining both official ratification and in the subsequent way partners have been able to operate and manage their alliances.

Historically, international alliances in aviation can be traced back as far as 1945 when the IATA was established primarily to coordinate international air fares. The bilateral structure of agreements that emerged following the inability of the 1994 Chicago Convention to initiate free international aviation markets regulated fares, routings, schedules, designated carriers and often embraced revenue pooling. The primary aim of the immediate post-war structure was to protect non-US carriers at a time when, as a result of the Second World War, the US had built up a dominant fleet of aircraft that could be transferred to commercial uses. Subsequently, the regime was often used to protect economically inefficient state owned carriers from the rigors of market competition.

The late 1980s and early 1990s saw the growth of new forms of international alliances that have embraced somewhat different characteristics and that serve different purposes. They have been less institutionalized in that they have generally been formed by privately owned commercial airlines outside of any governmental or inter-governmental agency initiative. The main growth has also been in international alliances. The first of these, between American Airlines and Qantas, was signed in 1985. The number of alliances involving US carriers then grew rapidly until by 1992 there were 61.

Alliances are also in a continual state of flux. According to the *Airline Business* survey, for instance, the Spanish carrier Iberia reduced its alliances from 27 in 1995 to 13 by May 1996. Over the same period Austrian Airlines canceled six agreements and added four new ones, Swissair added six agreements and dropped three while United Airlines canceled six but added two. These changes generally are part of a tidying-up processes as carriers formulate more coherent network strategies.

The exact number of airline alliances that now exists is unclear, not only because of the dynamic nature of the arrangements that make it almost impossible to keep abreast of changes but, also because the term 'alliance' is a generic one with no precise definition. It can, in a strict legal sense, mean some degree of equity ownership of one carrier by another but it is more often interpreted in looser terms to embrace such things as code-sharing agreements, interchangeable frequent flier programs and coordinated scheduling of services. Equally, airlines are often involved in a large number of different alliances, sometimes embracing a single partner but may involve several others carriers. A more recent feature is that increasingly several major carriers are linking their activities in so-called 'galaxies'.

An annual survey by *Airline Business* attempted to track alliances involving the major carriers and to report changes in the main features of the alliances (Table 1). The growth in strategic airline alliances is immediately obvious as is both the relatively small quantitative importance of alliances involving an equity stake and the slow growth in their numbers. The data presented is not, however, definitive and one finds, for instance, *The Economist* in 1995 producing slightly different figures and claiming that there were then 401 alliances,

double the number it estimated four years earlier. The overwhelming, conclusion, though, is that the number of alliances is large and increasing.

Table 1. Airline alliances 1994-1996

	1996	1995	1994	%change
Number of alliances	389	324	280	38.9
With equity stakes	62	58	58	6.9
Without equity stakes	327	266	222	47.3
New alliances	71	50	-	-
Number of airlines	171	153	136	25.7

Note: New alliances are those entered into since around May of the previous year and not then listed as planned. Alliances restricted to frequent flier co-operation were included in 1994, but excluded in 1995-6. The actual number of alliances in 1994, the first year *Airline Business* compiled information, was marginally higher than stated as some alliances went unreported. However, some domestic regional operators owned by majors were included in 1994, but excluded in 1995-6.

The North Atlantic market embraces a number of major strategic alliances that involve the airlines code-sharing and cooperating in other ways across a large number of routes so as to strategically link their networks. This type of strategic alliance dates back to the formation of the Global Excellence alliance formed by Swissair, Singapore International Airlines and Delta in 1989.

Other alliances, such as that between Continental and Alitalia and United and British Midland, are regional in their orientation involving code sharing between specific regions. The vast majority of alliances, 'point-specific' alliances, are, however, relatively minor, targeted affairs that usually generate few controversies. Blocked-space agreements are often a feature of point-specific alliances with airlines purchasing and reselling blocks of seats on each others flights.

Point specific alliances, in their various guises, may in some cases lead fears of to the prospect of monopoly domination of an individual route. The multifaceted, strategic alliances in which the large international carriers are increasing becoming engaged are now seen as potentially posing challenges of a somewhat greater magnitude (US GENERAL ACCOUNTING OFFICE, 1994).

In detail, alliance arrangements may take a number of different forms (BUTTON, 1997).

Full mergers of domestic airlines were a feature of the US domestic market following deregulation under the 1978 Airline Deregulation Act as the initial period of instability moved into one of consolidation and rationalization. For example, of the 34 new jet scheduled carriers to enter the US market between 1978 and 1992 only 2 remain operating with the vast majority of the others being merged with incumbents. Mergers of this type are the most extreme form of alliance and have been a traditional way in which carriers can coordinate their operations and other activities. They are claimed to enjoy the advantage that complete control of a carrier is in the hands of a single board and that resources can, therefore, be allocated more effectively.

In practice, though, mergers are not always successful. As a generalization, mergers linking overlapping networks in any transport industry tend to offer fewer economies than those that combine interfacing networks (either in geographical terms or with respect to the types of service offered). In some instances problems also arise because those involved have miscalculated the costs of transition.

Mergers generally involve the need to obtain institutional approval from various authorities. Traditionally, in virtually all cases cross-border mergers are not possible because of regulations limiting the degree of permitted foreign ownership in an airline. A notable exception to this being the joint ownership of SAS. Cross-border mergers also pose problems in terms of the implications for international air transport agreements since the nationality of a carrier can become blurred in these circumstances.

Even within countries mergers are often controlled by national governments although the degree of control can vary. In the US, for instance, the Department of Transportation took a very passive stance on mergers following deregulation of the domestic market. Individually, European countries have taken a variety of positions as has the EU in recent years. In many cases mergers, such as those between British Airways and British Caledonia and Air France and UTA, have only gained approval by the airlines relinquishing routes or slots.

The strongest form of airline alliance short of direct mergers or take-overs involves either unidirectional (as with the USAir/British Airways and Northwest/ KLM alliances) or cross-equity holdings. While mergers still take place, more recently there has been a tendency for the level of equity holdings to fall short of a full merger (Table 2). This is particularly so when airlines from two countries are involved and national laws limit the extent of foreign ownership. What the table does not show, however, is the degree of control that equity holdings can afford an airline and, in particular, voting rights are often less than the relative amount of capital involvement.

Table 2. Foreign ownership of major airlines

Country	Airline	%	Country	Airline	%
EUROPE			NORTHAMERICA		
Austria	Austrian	20	USA	America West	
	Lauda	40		Continental	20
Belgium	Sabena	49		Delta	20
France	TAT	49		Hawaiian	10
Germany	Deutsche BA	49		Northwest	33
Hungary	Malév	30		USAir	24
Luxembourg	Luxair	13	Canada	Canadian	22
Russia	Air Russia	31			33
UK	AirUK	45	AUSTRALASIA		
	BMA	40	Australia	Qantas	29
			New Zealand	Ansett NZ	100

Source: *Airline Business* December 1995

The relative importance of airline alliances involving equity stakes tends to be declining with *Airline Business* recording less than 16% of agreements in May 1996 involving equity investments compared with 18% in 1995 and 21% in 1994. This, nevertheless, does not mean that there has not been a large increase in their absolute numbers and other surveys indicate that from 1992 ownership stakes of above 20% have predominated.

Potential travelers have traditionally suffered from a dearth of information regarding the air transport options open to them. The problem was compounded from the late 1970s as fare deregulation and the widespread adoption of yield management techniques by airlines introduced a massive array of continually changing fare options. The use of computer reservation systems (CRSs) provides the interface between the carriers and the potential travelers. Airlines combine to make use of the information channels provided by CRS systems to stimulate their joint traffic flows. This involves code-sharing. Code-sharing is

now often seen as the main feature of any airline alliance and the number of code-shares has grown considerably in recent years.

Technically, a code-share is a marketing arrangement between two carriers that allows them to sell seats on each other's flights under their own designator code. In the case of connecting flights of two or more code-sharing carriers the whole flight is displayed as a single carrier service on a CRS. From the customers' perspective what it does is to give the impression of an on-line service or, at the least, offer some features of an on-line service such as single check-in, common frequent flier program and coordinated flight schedule. Code-shares can be across a wide range of services, as with the major strategic alliances but more often just involve a single service or a small network of services. A stronger form of code sharing involves blocked space arrangements. In this case one carrier buys space on another airline's aircraft that it then sells in its own right and using its own designator code.

Hub-and-spoke operations, and in particular the 'banking' of flights, that are a concomitant of effective hub-and-spoke operations, can be more efficient if carriers coordinate their flight schedules. Hub-and-spoke operations, by allowing traffic to be consolidated and transshipped between flights can enhance load factors and allow airlines to reap any economic benefits of economies of scope and scale that exist. By agreeing to coordinate schedules two allied airlines can increase the potential amount of traffic that on-lines across their combined networks.

Franchising has been almost a tradition in sectors such as fast food and clothing. Its appeal in aviation is that it allows a major carrier to spread its brand name and generate revenues on thin routes without the necessary commitment major capital investments. It is now a form of alliance that is growing in popularity in international markets and especially in Europe where British Airways has been particularly successful in developing franchising activities. Some other carriers have been less enthusiastic about franchising arrangements and have been slower to adopt them.

The aviation safety equation

The incentive for any airline to provide safe services is the potential for lost business that it would suffer if its accident rate or, more strictly, its perceived accident rate, exceeded the net benefits that passengers enjoy from making use of its services. Safety is one of the attributes of an airlines' characteristics that potential customers, and subsequently investors, look at in making decisions². This inherent market pressure is boosted by regulations and codes of conduct imposed on the industry by government. Government involvement is usually justified because of imperfections in the market that make it impossible for potential passengers to understand fully the risks confronting them or, even if information is adequate, have insufficient market power to ensure levels of safety are optimized.

One simple way of looking at air transport safety from an analytical point of view is to think in terms of the incentives that influence the actions of those providing air transport services. Essentially, the incentive function takes the general form:

² Safety is a very general term for which there is no strict definition. This is because accidents can take a variety of forms and be of differing intensity. Also the actuarial probability of an accident may differ from an individual's perception of the chance of being in an accident (MOSES and SAVAGE, 1990). No attempt at a strict definition of safety is offered here but rather the subject is treated in general terms.

$$S = f(E, G, I) + \epsilon$$

(1)

where:

- S reflects the safety standard level adopted by an airline,
- E reflects the private economic incentive to be safe (e.g. reputation, insurance premiums, lost business, share price and the interest of flight personnel);
- G represent the government safety codes and policies (e.g. regarding aircraft safety features, maintenance standards and crews working hours and conditions);
- I represents infrastructure considerations (e.g. airport design and air traffic control).

There is an additional random element in the function, ϵ , indicating the risk of someone else, such as a missile or bomb, causing the accident³.

With respect to safety levels pursued by a carrier, there is no reason to assume that it is socially desirable for an airline to be 100% safe. There are opportunity costs associated with devoting resources to safety and it is clear from individuals' decisions on such things as the speed they drive at or the choices they make regarding car travel over air travel that factors such as time savings or cost saving often over-ride safety considerations. Indeed, many argue that aviation is excessively safe and with better information about relative safety records society would put less resources into aviation safety (KAHN, 1988).

Regarding the items on the right hand side of the equation, while these may be expressed as independent factors they will, in practice almost certainly exhibit some degree of correlation. The nature of infrastructure provision, for instance, is inevitably linked to the safety regulatory regime adopted by the authorities. Equally, the internal economic incentives influencing an airlines pursuit of safety cannot be completely separated from the institutional regime within which the carrier operates. Nevertheless, the three-way division is helpful in tying together the implications of globalization and strategic alliances with aviation safety considerations.

Strategic airline alliances and the safety equation

If we consider equation 1 then there are a number of ways in which changes in the institutional structure of the airline industry, including the creation of strategic alliances, can have a bearing. These are both in terms of the internal structure of the airlines' operations and in the ways in which the authorities may respond to them.

What we do not have at present is a very large body of rigorous empirical evidence linking strategic airline alliances to safety questions. Alliances are too new for detailed statistical analysis of the type required; short term fluctuations in airline accidents rates involving a very small number of incidents does not make for easy econometric work. What one, therefore, must generally rely on in looking at the safety implications of alliances are parallel experiences of aviation developments that have also influenced the structure of the sector and on anecdotal evidence gleaned from the experiences of alliances to-date..

- **Aggregate air travel demand**

The creation of strategic alliances is claimed in a number of studies to generate, when controlled within an appropriate economic regulatory regime, significant consumer benefits (e.g. US GENERAL ACCOUNTING OFFICE, 1995; UK CIVIL AVIATION AUTHORITY, 1994). In

³ The issue of terrorism and the growth of strategic airline alliances is outside of the domain of this paper.

particular, the various economies enjoyed by carriers combined with service enhancements and lower fares for users have lead to more travel by air; the latter being a reflection of enhanced consumer surplus. This, however, only occurs provided carriers do not excessively exploit any monopoly powers associated with the market strength that alliances could potentially generate.

More air travel beyond the increase that would occur without the growth of alliances would of itself lead to more aviation accidents according to the arguments present by Boeing in 1996. The added economic efficiency that alliances bring about and the accompanying additional traffic will inevitably increase the potential aggregate number of aviation incidents. Public policy (G in equation 1) is inevitably going to respond to this. In the US, for example, the Federal Aviation Authority (FAA) has already began releasing more information on safety in an effort to keep the public better informed, although the complexity of aviation safety issues suggests that such information will in practice not really offer any great insights⁴.

Equally, in terms of I in equation 1, the provision of and use made of aviation infrastructure may be changed. At present many airports and air traffic systems are working at, or above their design capacity and are also, in many cases, using out-dated technologies. There will be enhanced pressures both from a purely air transport perspective and from a safety standpoint to ensure that existing infrastructure is used better and new infrastructure provided where justified.

There is, though, another way of looking at this aspect of the safety issue. What is missing from many calculations on the implications of increased demand for air travel is the opportunity cost element. If individuals were not traveling by air they would be engaged in some other activity that of itself has a safety aspect attached to it. In this sense, it is not altogether clear that more air travel will result in more deaths and injuries in aggregate.

Little empirical work has been conducted into this aspect of airline safety. What evidence there is mainly relates to experiences with domestic airline liberalization in the US after the enactment of the 1978 Airline Deregulation Act (ROSE, 1989; MORRISON and WINSTON, 1988; OSTER, and ZORN, 1989). The limited amount of analysis undertaken here indicates that on many routes where US airlines could compete with automobile travel then the diversion effect from car to plane as the result of improved services offered by airlines reduced the number of road deaths. The calculations are made difficult, however, because of the inherent problems in defining counterfactuals, but BYLOW and SAVAGE (1991) estimate some 275 highway fatalities were avoided by the modal switches to air travel.

Not only are the US estimates very tentative for technical reasons, but extrapolation to the effect of strategic airline alliances poses particular difficulties. While the alliances do involve situations where new structures of fares, services and routes can induce modal transfers, many of the really important alliances focus on long distance travel, often over oceans, where commercial aviation is the only via transport option⁵. What the alliances do

⁴ MOSES and SAVAGE (1990) make the argument that after any institutional change, the safety authorities may adjust their preferred level of safety - essentially recognizing that the economic benefits associated with the new regime are worth trading for possibly lower safety criteria. This does not, however, mean that no safety reforms are needed to meet this new safety standard; put simply all the parameters have shifted and adjustments may be needed to safety regulations etc. to allow for this even at a new safety level.

⁵ There still remains the broader issue of what induced travelers would have done with their time even they would not have been traveling by an alternative mode of transport.

seem to do within the narrow confines of transport is to induce travelers away from carriers outside of alliances. This, for instances, is seen very clearly in the analysis that has been completed on the strategic alliances affecting the North Atlantic market where the KLM/Northwest and British Airways/USAir alliances demonstrably took traffic from competitors (GELLMAN RESEARCH ASSOCIATES, 1994; US GENERAL ACCOUNTING OFFICE, 1995). From the safety perspective, the issue then becomes one predominantly of discovering whether the alliance carriers are safer than their non-alliance counterparts. This issue is addressed separately later.

• **Consumer information**

Airline alliances affect the type of information that travelers enjoy regarding the actual carrier they fly with. As can be seen from Figure 1, that provides a simple schema of the links involved for Swissair in the Global Quality alliance in 1994, alliance structures can become very complex. It is not difficult to see, in this case, why, for instance, someone booking a multi-segment flight with Swissair could be puzzled at being carried on a Delta aircraft. Blocked space agreements are potentially even more confusing.

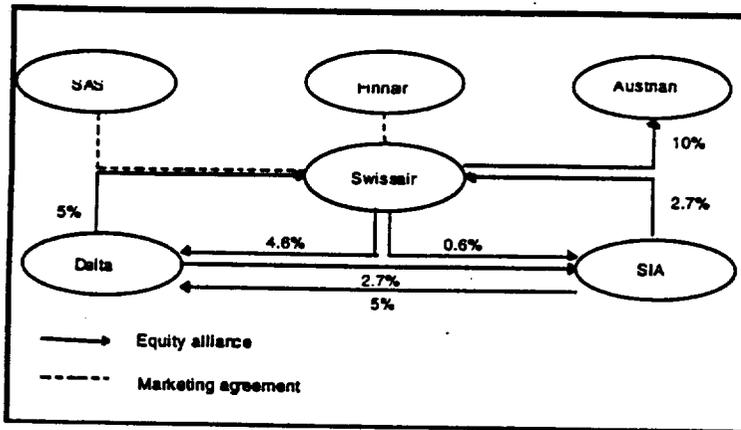


Figure 1. Swissair and the Global Quality alliance 1994.

In terms of safety, consumer information raises two important questions; these concern the identity of the carrier actually taking the passenger and the type of aircraft used for the flight⁶.

Although the variations are very small, airlines do have differing historic safety records. This is not only in terms of the number of accidents they have experienced but also relates to the degree to which they have been held negligent for accidents. Airlines also offer different frequencies, qualities of service and fares. In a perfect world, potential passengers should be able to make their choices and trade-off the various attributes of carriers when selecting the airline they wish to fly. In the case of alliances, it is often

All human activities have risks of accidents associated with them and many of those exceed those risks to do with flying.

⁶ There is also the supplementary issue of who is responsible for an accident involving passengers from several airlines on an alliance flight and how is compensation to be extracted. This is not dealt with here.

difficult to know exactly what are the various portfolios that are available because the actual carrier providing the flight is not immediately transparent.

There have been public policy efforts to ensure that alliance code-sharing arrangements are not used to misinform or disadvantage passengers. This involves not just direct issues revolving around individuals having information on the exact airline they will travel on but extends to such things as responsibility for missed connections, direction to connecting flights and ensuring appropriate information systems are available at airports. To prevent screen padding on CRS systems the European Union now limits codeshared flights to being displayed twice. The United States has no such limit on displays in this way. What the US rules do require is that passengers are informed by US airlines of the actual carrier with which they travel. The European Civil Aviation Conference (ECAC) has a similar code for disclosure but is not legally binding on member states.

It is not just airlines that have differing safety records, aircraft also do⁷. There are arguments that that potential travelers' perception of the safety of different aircraft types can affect their decisions and that information on plane types should be transparent. Airline alliances could hide or make it more difficult for passenger to have information regarding aircraft type.

The most documented case of the commercial impact of an aircraft crash on its producer relates to the McDonnell Douglas DC-10 after two major crashes (one in 1979 and the other in 1989). Here there was evidence of significant falls in the producer's share prices immediately after the 1979 incident that could only be accounted for in terms of lower anticipated sales (CHALK, 1986). KARELS (1989) extended this analysis to look at the share prices of airlines such as American that flew DC-10s and found that their share prices were also adversely affected after the accident⁸. In contrast to this the 1989 DC-10 crash seemed to have no long term adverse effects on the McDonnell Douglas' share prices. There is also no evidence that the share prices of Boeing or Lockheed have fallen significantly affect an accident suggesting the impact of the 1979 DC-10 crash was atypical (CHALK, 1986).

• Alliances versus non-alliance carriers

One very vocal concern expressed at the time of the liberalization of the US domestic air transport market in 1978 was that free markets would force some carriers to cut corners with regard to safe operations to keep their fares competitive. The argument was resurrected after a series of accidents in the mid-1980s and the fining of a number of carriers for violating maintenance and safety regulations (NANCE, 1986). In fact the evidence seem to be that in this case market changes seem to have had little effect on the overall level and trend of accidents in the US market (MORRISON and WINSTON, 1988).

What the experience has shown, though is that there does seem to be variations in the inputs airline put into safety. The US National Transportation Safety Board, for example, expressed concern about budget constraints restricting maintenance although this may well have reflected the actual safety regulations in place for such operations (US CONGRESS,

⁷ In general, jet aircraft have a better safety record than turboprop aircraft but there are also difference within these two broad categories. For example, Boeing 747 (100, 200, 330 series) aircraft have about 1.6 crashes per million departures; Airbus A300-600 aircraft have about 1.4 per million departures while Boeing 737 (300, 400, 500 series) aircraft have about 0.5 per million departures.

⁸ Focusing on patronage rather than financial performance, however, BARNETT and LOFASO (1983) found that the crash had no impact on the market shares of routes where DC-10s were flown.

COMMITTEE ON GOVERNMENT OPERATIONS, 1977). Following deregulation in the US domestic market, a number of studies produced evidence of reduced expenditure on potentially safety related activities, such as maintenance and training, in some segments of the market (LEDERER AND ENDERS, 1989). Even if this did not produce more incidents immediately, there is an argument that in the longer term a legacy effect would result in accidents. Assessing the validity of this argument is not easy. Technical advances, especially in jet engines, has reduced maintenance needs and isolating this shift in the maintenance cost function from the impact of institutional changes is not easy.

There is also another set of findings of importance, namely linkages between the actual financial position of an airline and an airline's accident record. ROSE (1989; 1990) finds in analysis of US domestic carriers, that there was a one year lagged positive effect on accidents rates of higher operating profits although the effect is negligible amongst the largest carriers.

Where does this lead with regard to the growth in strategic alliances? From the evidence obtained on North Atlantic routes, alliances tend to attract passengers from non-alliance carriers. One consideration relates to the financial pressures on alliance carriers; are the market pressures to cut corners on such things as maintenance and to employ cheaper, less experienced crew greater for alliance carriers. In general, the evidence is that alliance carriers, especially when there are mergers or equity holdings involved, have a larger resource base and are, therefore, less prone to liquidity difficulties. Indeed, in the case of many alliances (e.g. British Airways/USAir; KLM/Northwest and American/Canadian) significant financial injections were made by one partner into the other to bolster a flagging financial position. This suggests, *a priori*, that many alliance airlines are in stronger financial positions than they would be operating in isolation. This in itself, though, may not mean overall improved safety even if it were true that a strong financial performance correlates with less accidents. This is because the non-alliance carriers on these routes would be the subject of greater financial pressures.

Comparisons between alliance carriers and non-alliance carriers also bring two other different elements into consideration.

First, blocked space alliance arrangements, whereby a carrier buys capacity on another plane, and coordinated scheduling by code-sharing partners can lead to the use of larger aircraft on the routes involved. The evidence that is available is that larger aircraft tend to be safer than smaller ones (OSTER and ZORN, 1989).

Second, and to complicate the situation, where alliances do in some way rationalize the use of the partners' capacity this can free up the market to allow new entry. This may come about for purely commercial reasons or it may be driven by institutional factors. For instance, in several mergers involving European carriers slot were relinquished by the partners to meet anti-trust requirements. Similar arrangements seem important in the efforts of British Airways and American to form a strategic code-sharing alliance. This raises questions as to whether the new entrants are safer than incumbents⁹. The evidence, which again is mainly from US experiences, is that there is little difference in the safety record of

⁹ One of the problems with the work that has been completed in this area is that many new entrants into scheduled aviation are not new to airline operations *per se*. In many cases they are charter carriers that have extended their operations (LEVINE, 1989). This may not have been a problem in the past, after all where the newcomers originate from is not relevant to the safety equation which is merely concerned with the implications of a change in supply on accidents, but in many markets there are now more genuinely new airlines and their potential safety characteristics are now important.

established carriers and incumbents measured in terms of accidents (OSTER, and ZORN, 1989; ROSE, 1989)¹⁰.

The airline switch effects of strategic alliance on safety are, therefore, far from clear. It does not seem, however, that there are strong forces likely to lead to reduced safety as a result of the way traffic may switch between airlines once an alliance is formed in a particular market. Indeed, there could be made a case that if anything the changes would, on balance, have a positive effect on safety.

- **Managerial incentives**

There are also a number of other ways in which the E component in equation 1 may change as a result of alliances being created. Does the establishment of an airline alliance, for example, influence the management incentive of the partner carriers to change their approach to safety? The available evidence is not altogether conclusive as to the implications for airlines of accidents. Much depends on the circumstances involved and on how the airline manages the crisis.

One argument is that accidents will discourage people from using the carrier concerned even after the immediate impact has passed (BORENSTEIN and ZIMMERMAN, 1988). While this may or may not be true, measurement of this effect is made difficult by the natural response of any carrier which is adversely affected in this way to lower fares so as to keep its market share (ROSE, 1990; 1992). The airline in a sense is lowering its price to compensate for any public perception of a lower generalised quality of service.

An alternative way of looking at the topic is the impact of accidents directly on the financial status of an airline. Simply eye-balling the share prices of ValuJet and TWA (Figure 2) shows significant declines in their respective share prices (both actual and against a moving average) following crashes involving their aircraft in May 1996 and July 1996 respectively¹¹. The contrast is particularly clear when compared to American Airlines¹². American did, though, experience a major crash during this data period, the loss of a Boeing 757 in Columbia during December 1995, but this does not seem to have adversely affected the smoothed share value index. The difference would seem to lie in the location of the crash, the American incident being outside of the US, and in the perception of whole was at fault.

This rather uneven pattern of stock market implications is in conformity with more rigorous studies that have been completed looking at the financial implications for an airline of crashes. In this context there has been work on a number of themes, much of it concerned with US experiences¹³.

¹⁰ Incidents involving new entrants, other things being equal, however, tend to result in more fatalities possibly due to the lesser experience of pilots.

¹¹ The ValuJet case is complicated by the temporary closure of the airline by the FAA for violation of safety and maintenance codes just after one of the airline's DC9s crashed in Florida.

¹² This lack of any apparent immediate link between airline safety records and profits is also consistent with the findings of GOLBE (1986).

¹³ Outside of the US, the *Edwards Report* in the UK concluded in 1969 that independent operators were less safe than regularly licenced carriers for the period 1955 to 1966 and that smaller carriers and charter operators were more susceptible to accidents.

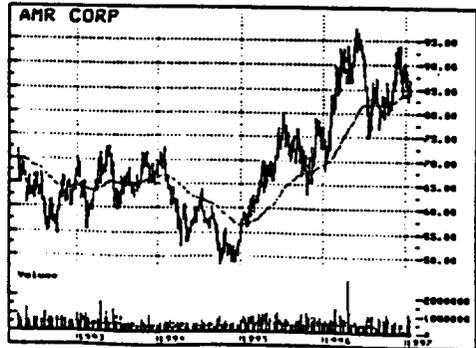
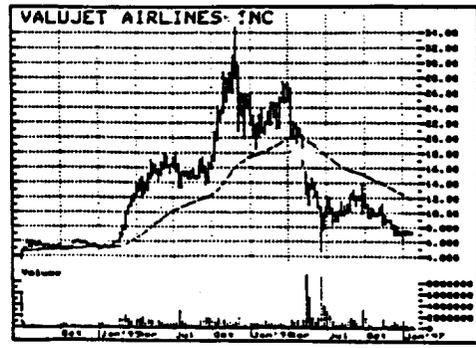
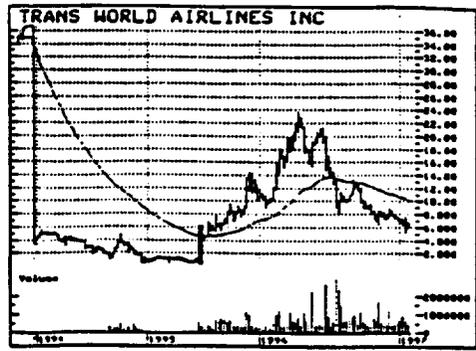


Figure 2 . Share prices and volume of trading for TWA, ValuJet and AMR.

An accident seldom costs an airline in terms of immediate payments because all carriers tend to be extensively, and frequently excessively, insured. What it may do, however, is to affect an airline's image and to impact on future insurance premiums it must pay. MITCHELL and MALONEY (1989), for instance, looked at insurance rate adjustments after crashes and 'brand name effects' and found that share price falls can be attributed both to the projected future costs of higher insurance and to a brand name effect associated at-fault attribution. In contrast to this, CHANCE and FERRIS (1987) find an immediate dip in share price of an airline involved in an incident, although it is extremely short lived, but no impact on the industry in general. GOLBE (1986) in his study of the early years of US domestic deregulation concluded, "There does not seem to be a statistically significant relationship between safety and profits". BORENSTEIN and ZIMMERMAN (1988), in contrast found that airlines suffered an equity loss of about 1.0% as a result of an accident. The picture is not, therefore, very clear on this topic.

Where does the establishment of alliances fit into this picture? Much depends upon the nature of an alliance. If the structure is extremely loose then there would seem to be little reason or pressure for the management of any carrier to change its behavior patterns with regard to safety. Where there is, however, a closer relationship, especially involving equity holdings, there may be grounds for expecting airlines to closely monitor each other's safety performance, especially if each fears that any diminution in reputation of one airline would adversely affect the other. Empirical evidence on this is simply not currently available as the strategic airline alliances are simply too new and their structures too variable to allow any sort of detailed testing.

- **Lobbying power**

As well as looking at the implications of alliances for the internal effects they may have on airlines' attitudes towards safety and managements' reactions to this, airlines also often exercise considerable political power. In general large suppliers exercise more political power than do smaller ones and so one would expect alliances to have more political sway than individual airlines. Looked at in another way, airline alliances effectively change supply conditions, and therefore, this could potentially have implications for the G component of equation 1.

One possible way of looking at this more systematically is to treat those involved in supporting any aviation policy as a coalition (KEELER, 1984). Following this approach strategic alliances serve the interest of a number of different parties. In terms of an airline alliance acting to alter government policy on aviation safety one must look, in the context of coalitions, at the factors motivating those in the 'ruling coalition'.

There would seem to be little reason for the users of aviation to try to reduce safety standards unless they were initially felt to be excessive. From a competitive perspective, there would seem to be little reason for member airlines of an alliance to compromise on standards since, generally, they are the larger carriers that have solid safety records giving them a comparative advantage over non-alliance rivals. The exception to this is when an alliance has a monopoly position and it is to the combined advantage of the partners' to reduce overall safety standards and to save on their costs. There are few incentives for the bureaucracy responsible for safety to compromise on existing standards since this would reduce their power and influence. Equally, airline producers would seem to be little affected in their attitude to safety and in their lobbying positions by the formation of a strategic alliance.

What one can concluded from these few observations is that there is unlikely to be any significant changes in the attitudes of those concerned with alliances to manipulate public policy in a way that would be detrimental to current safety conditions.

Conclusions

Recently much debate has taken place concerned with the implications of strategic airline alliances on the efficient internal workings of aviation markets. Much less attention has been paid to the implications of strategic alliances for airline safety. In fact, air transport is extremely safe and any institutional change is unlikely to have more than a marginal effect on it. Nevertheless, in part because of the intensity of single incidents and in part because the media find it cost effective to cover the limited number of air crashes rather than the much more numerous but dispersed motor accidents, the public still remains concerned about aviation safety matters.

The strategic global airline alliances that represent the cornerstone of the internationalization of the aviation sector are in many ways still in an embryonic state. Large numbers of alliances fail. Contemplating their implications for safety is, consequently, far from easy. They also take many different forms. There does not, however, seem to be any justifiable reason to suppose that airline alliances will have any major adverse effect on aviation safety and, in some ways, they are likely to reinforce the strength of the safety record of the sector.

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SINGLE SCAN

Topic Area: A4

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**SCHEDULE COMPETITION, FARE COMPETITION
AND PREDATION IN A DUOPOLY AIRLINE MARKET**

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(Paper No. 92, revised version)

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1 INTRODUCTION

Since deregulation of the U.S. airline market twenty years ago, airline competition has been the subject of intensive research. Interest has been sustained by the ongoing evolution of the U.S. market, deregulation in Canada in the 1980s, and the evolutionary process of deregulation underway in Europe.

Competition between airlines occurs in various dimensions, including fares, capacity, flight schedules, frequent flier programs, computer reservations systems, code-sharing agreements and alliances. This paper focuses on competition in fares and flight schedules. Fare competition has been the subject of many studies in the literature. The importance of schedule frequency has also long been recognized; see for example Douglas and Miller (1974), Panzar (1979), Dorman (1983), Hansen (1990) and Norman and Strandenes (1994).

The timing of flights is clearly another important factor determining the attractiveness of an airline because of traveller's preferences for when they depart and/or arrive. Because flights can be viewed as products located at points in time around the twenty-four hour clock, the considerable literature on spatial price and location competition can be brought to bear. However, certain features of airline markets have yet to receive a definitive treatment in this literature, and there have been few applications to airline markets *per se*. One recent contribution is Daniel (1995) who estimates a model of airline flight departure/arrival time choice. Airlines in his model trade off queuing time at airports and schedule delay costs. Neither business stealing between rival airlines nor fare competition is considered. Another recent study is Encaoua *et al.* (1996) who develop a model of duopolistic competition on a simple network. The airlines engage in a two-stage game, choosing departure times for their flights in the first stage and fares in the second. While illuminating, their model has several restrictive features, including only one flight per airline on each route, a uniform distribution of the traveller population in terms of desired departure time, and price-inelastic aggregate demand.

Another focus of this paper is predation in airline markets. Predatory behaviour can take various forms: increasing seat capacity by adding flights or using larger planes, matching rivals' flight schedules, offering deep discount fares, *etc.* Descriptive evidence of such behaviour has been documented in several markets, including British Airways against Loganair on the Edinburgh — Manchester route (Hanlon, 1994), Northwest Airlines against People Express on the Minneapolis/St. Paul — Newark route (Kahn, 1991), and Air Canada against Canadian Airlines International on routes in Canada (Tomaszewska, 1997).

Predation has been the subject of considerable theoretical economic research, and there are a few empirical studies of alleged predatory behaviour in terms of product location (*e.g.* supermarkets by Von Hohenbalken and West (1984), and city bus markets by Dodgson and Newton (1992) and Dodgson *et al.* (1993)). There are also some insightful discussions of predation in airline markets; *e.g.* Kahn (1991) and Hanlon (1994). But there has been little formal analysis of airline predation by any means and, to the best of our knowledge, none of

predatory behaviour in departure time scheduling.¹

The purpose of this study is to explore both nonpredatory and predatory flight schedule and fare competition using a Hotelling-type spatial competition model. The market considered is a single city pair served by two airlines. The airlines play a two-stage noncooperative game, choosing the timing of their flights in the first stage, and fares in the second stage. The numbers of flights offered by each airline and the seating capacities of flights are treated parametrically. Subgame perfect equilibria to the two-stage game are computed numerically using an iterative tatonnement-like procedure.

Section 2 of the paper develops the model, including variants that incorporate flight capacity constraints and predatory behaviour by one of the airlines. Section 3 describes nonpredatory and predatory equilibria of the model for two hypothetical markets. Section 4 provides a summary, and suggests directions for further research.

2 THE MODEL

2.1 Basic specification

Consider a single city pair market served by two airlines, indexed $i=1, 2$. Airline i has N_i flights that it schedules for departure at times $X_i \equiv (x_{i1}, \dots, x_{iN_i})$. Departure times are chosen on the 24 hour circle. Airline i 's j th flight is denoted F_{ij} . The airline chooses a vector of fares $p_i \equiv (p_{i1}, \dots, p_{iN_i})$, where p_{ij} is the single fare² for F_{ij} . For reasons of computational tractability potential travelers are aggregated into mass points, indexed $k=1 \dots K$. Mass k has population m_k and a preferred departure time $x^k = (k/K)T$, where $T=24$ is the length of the day in hours. Individuals incur quadratic schedule delay costs from departing at other than their preferred times. An individual in mass k who takes flight F_{ij} pays a generalized cost $p_{ij} + t(x^k - x_{ij})^2$, where t is a parameter that measures the strength of departure time preferences.

Traveler behaviour is described by a discrete choice model. Each individual has three decisions: whether to fly, and if so with which airline and on which of its flights. An individual in mass k choosing F_{ij} receives a utility $U_{ij}^k = a_i - p_{ij} - t(x^k - x_{ij})^2 + \tilde{\epsilon}_i$, $\equiv V_{ij}^k + \tilde{\epsilon}_i$, where a_i is a constant that is common to everyone, $\tilde{\epsilon}_i$ is an individual-specific (not mass-specific) idiosyncratic utility for airline i , and V_{ij}^k denotes systematic utility. The a_i coefficients can differ between airlines because of differences in actual or perceived quality (*viz.* in-flight service, on-time performance, baggage handling, safety and so on). Idiosyncratic individual preferences for airlines can arise because of differences in personal flying experience, or differences in memberships with frequent flier programs and usage of

¹ Tomaszewska (1997) tests for predatory pricing and capacity expansion by Air Canada against Canadian Airlines International over the period 1988-1994.

² The model thus abstracts from multiple fare classes that airlines typically operate through airline seat management programs.

them.³ The model thus includes elements of both horizontal and vertical production differentiation between airlines.

Individuals in mass k who fly with airline i choose its flight with the lowest generalized cost: $j_i^{*k} = \underset{j}{\text{Argmin}} p_{ij} + t(x^k - x_{ij})^2$. Let V_i^{*k} denote their corresponding systematic utility. An individual from any mass who chooses not to fly receives a utility $U_0 = V_0 + \tilde{\epsilon}_0$, where V_0 is a constant that is common to everyone, and $\tilde{\epsilon}_0$ is individual-specific utility for money spent on other goods. If the $\tilde{\epsilon}_i$ and $\tilde{\epsilon}_0$ are identically and independently distributed Gumbel variates with scale parameter μ , then the probability that an individual in mass k flies with airline i is given by the familiar multinomial logit formula:

$$\phi_i^k = \frac{e^{V_i^{*k}/\mu}}{e^{V_1^{*k}/\mu} + e^{V_2^{*k}/\mu} + e^{V_0/\mu}}$$

Because the numbers of flights scheduled by each airline are treated as given, the fixed costs of flights are immaterial to the analysis and are normalized to zero. Marginal costs of passengers can be deducted from the a_i (see below) and accordingly are set to zero also. The variable profits of Airline i , π_i , then coincide with its revenues, which are given by the formula

$$\pi_i = \sum_{j=1}^{N_i} p_{ij} \left[\sum_{k=1}^K m_k \phi_i^k \phi_{j\mu}^k \right],$$

where $\phi_{j\mu}^k = 1$ if $j = j_i^{*k}$ and $\phi_{j\mu}^k = 0$ otherwise.

Airlines are assumed to maximize variable profits and to play a noncooperative two-stage game.⁴ In Stage 1 they simultaneously choose their flight schedules, X_1 and X_2 . In Stage 2 they choose their fares, p_1 and p_2 . How these choices are implemented is described in the next subsection.

2.2 Computation of equilibrium

Equilibria are computed numerically using an iterative "tatonnement" procedure. The timing of each flight is constrained to the set $\{\Delta x, 2\Delta x, 3\Delta x \dots T\}$, where Δx is a time step that divides evenly into T . Initial schedules X_1^0 and X_2^0 are chosen for each airline. A grid search is then performed over a time interval $[x^{\min}, x^{\max}]$ within which the equilibrium

³ Idiosyncratic preferences for the flights of a given airline could also be introduced. This was initially done using a nested logit framework, but difficulties were encountered in getting the algorithm (described below) to converge. Arguably the main differences between flights are their departure times, and preferences for flight times are accounted for in the model.

⁴ Both explicit and tacit collusion between airlines are ruled out. Evidence that airlines do behave noncooperatively is reported in Brander and Zhang (1990), Good, Roller and Sickles (1993) and Neven and Roller (1996). In contrast, Evans and Kessides (1994) find that fares are higher on routes served by carriers with extensive interroute contacts. Such carriers may refrain from aggressive pricing on a given route for fear of retaliation on other routes. Such behaviour would be tacitly collusive.

schedules can be reasonably assumed to lie.⁵ The grid search is first done for Airline 1's flights, then Airline 2's, then back to Airline 1's and so on. Throughout, the order in which each airline's flights are scheduled is preserved. Thus, x_{1j} is incremented in time steps of Δx over the interval $[x^{\min}, x_{12} - \Delta x]$ (or $[x^{\min}, x^{\max}]$ if $N_j = 1$) holding the timing of all other flights constant. For each value of x_{1j} a fare equilibrium for all flights of both airlines is computed using another tatonnement procedure similar to that described in de Palma *et al.* (1994). When the rescheduling of F_{1j} is completed, x_{1j} is fixed at the value that yields the highest π_i . Next, a grid search is performed for x_{12} over the interval $[x_{11} + \Delta x, x_{13} - \Delta x]$, and so on. Sister flights are prevented from locating at the same time, but can coincide with a rival flight. When all of Airline 1's flights have been shuffled, the procedure is repeated for Airline 2. This completes one major iteration of the search. Major iterations continue until there is no change in either airline's schedule between successive iterations. An equilibrium is then deemed to have been reached.⁶

2.3 Capacity constraints

The model described in Section 2.1 ignores the fact that the number of passengers that can be accommodated on a flight cannot exceed the plane's seating capacity. One way to incorporate capacity constraints is to treat a flight as a congestible facility for which utility decreases with the number of people who use it. This approach has been taken by Panzar (1979), Dorman (1983), Kohlberg (1983), and Rietveld and Rouwendal (1996). A second approach is to treat a flight as a loss system, in which each traveler is either accommodated at a constant quality, or not accommodated at all (Powell and Winston, 1983; Inzerilli and Jara-Diaz, 1994). In this paper flights are treated as loss systems. It is true that some aspects of flight quality deteriorate with the load factor, such as time to board, deboard and retrieve baggage, space in overhead luggage compartments and speed of in-flight service. But being able to fly at all is arguably the predominant consideration for travelers.

Space constraints preclude a complete description of the approach, but the essentials are as follows. Individual travel demands are stochastically generated during the weeks prior to the day of travel in question. The rate of demand generation is the same for all potential travelers; *i.e.* independent of both preferred departure time and idiosyncratic preferences. Aggregate demand is deterministic (a Law of Large Numbers is at work). As demand is generated, it is loaded onto flights according to individual preferences in the way described in Section 2.1.⁷ If a flight fills up, it is removed from travellers' choice set. Loading ends when each prospective traveler is either booked on a flight, chooses not to fly, or wants to fly but can't because all flights are full. Finally, the algorithm described in Section 2.2 is

⁵ In practice flight times may be constrained by airport ordinances that limit operating hours.

⁶ This procedure is similar to that employed by Ansari *et al.* (1994). The sequential "shuffling" of schedules is not guaranteed to reach a global profit maximum for each airline in any major iteration of the algorithm. But the alternative of conducting a grid search over all possible schedule configurations would be slower, and is impractical when airlines have multiple flights.

⁷ The loading procedure is inspired by Powell and Winston (1983). Their procedure is different however because aggregate demand is random in their model.

used with only minor changes to compute equilibrium.⁸

2.4 Predation

Predation has been a longstanding and controversial research topic in economics; see Ordoover and Saloner (1989) for a review. Predatory behaviour by a firm can have various objectives, including forcing a rival to exit from the market, deterring future entry or, less drastically, inducing a rival to withdraw capacity, raise prices, or otherwise adopt a less aggressive posture. Typically, predation involves a loss of profits in the short run in return for higher future profits if the strategy succeeds.

One possibility is that a rival will 'capitulate' if its profits, or perhaps cumulative profits, fall below a predetermined threshold. Hanlon (1994) discusses this possibility in an airline market setting. In many circumstances, however, a predator will be unsure about how long it will take for aggressive behaviour to pay off, or indeed whether it ever will. Uncertainty is endemic to airline markets. Demand for air travel fluctuates unpredictably with the state of the national or world economy. Demand shocks can occur, such as the downturns that followed the 1990-91 Gulf War and the recent Asian economic crisis. Airline costs fluctuate with exchange rates and fuel prices. And there may be uncertainty about the depth of a rival's financial pockets, or the possibility of government intervention or bailout.⁹

Given these uncertainties it seems appropriate to take as the predator's objective function its long-run expected present discounted profits, where the probability in each time period of a favorable change in the rival's behaviour is a decreasing function of the rival's profits. Suppose Airline 1 is the predator and Airline 2 the rival or "victim".¹⁰ In our model, with the numbers of flights assumed fixed, predation can involve changes in schedules and/or fares. The first-order condition for the fare of Airline 1's j th flight will take the form

$$\frac{\partial \pi_1}{\partial p_{1j}} - \delta \frac{\partial \pi_2}{\partial p_{1j}},$$

where $\delta > 0$ depends, in a possibly complicated way, on Airline 1's long-run objective function. An analogous condition obtains for x_{1j} . The intertemporal linkage between Airline 1's strategy in the current period and its future profits can be implemented in our static model framework simply by adopting as Airline 1's objective function $\pi_1 - \delta \pi_2$.

⁸ Recall that the algorithm preserves the departure order of each airline's own flights. This is inconsequential as long as the planes are identical (*viz.* have the same capacity), which is assumed for the simulations in Section 3.

⁹ For example, after many months of suspense about its survival, in December 1992 Canadian Airlines International signed an investment agreement with AMR Corp., the parent company of American Airlines, and obtained loan guarantees of \$120 million (Canadian) from the Canadian federal government and the provincial governments of Alberta and British Columbia.

¹⁰ It is assumed that the victim does not engage in strategic behaviour itself. Opposing arguments have been made as to whether firms in financial distress compete more or less aggressively (Borenstein and Rose, 1995).

The numerical value of δ will depend on various factors, including the discount rate, the relative size of the two airlines, features of their route networks, the expected growth rate in demand, the hazard rate for a change in Airline 2's behaviour, the expected present-value profit gain to Airline 1 from a change, and the possibility of further evolution in market structure — such as entry by another airline or a change in regulation. A number of heroic assumptions are needed to quantify these elements, but it seems plausible that δ could exceed one.

In this framework, Airline 1 acts in a predatory fashion if it takes into account the impact of its actions on the future viability or behaviour of the rival. This definition is consistent with those recently proposed by Adams *et al.* (1996) and Cabral and Riordan (1997). In particular, predation entails behaviour that would not be optimal if the rival's future existence and behaviour were treated as given.

This framework can be criticized on the grounds that it treats one route in isolation, ignoring network aspects of competition that are important in today's airline markets. It is true that the scope for predation on a route may depend on an airline's ability to cover its losses with profits earned on other routes. And predation on one route may be intended to deter entry on an airline's other routes. Thus, a complete cost-benefit analysis of predation from the perspective of an airline would require consideration of its route network as a whole. However, the intertemporal tradeoff between current and expected future profits incorporated into the simple framework above remains valid in this bigger picture, as do the modified objective function and first-order conditions. Our purpose is to explore the implications of predatory behaviour on a given route, ignoring precisely what motivates the predatory airline to act in this way.

Table 1: Predation scenarios

Scenario	X_1	X_2	p_1	p_2
A	Fixed	Fixed		Fixed
B	Fixed	Fixed		
C		Fixed		
D				

Several predatory scenarios can be envisaged according to whether the predator adjusts its schedule and/or fares, and how the rival or victim responds. With today's sophisticated airline seat management programs and computer reservation systems, fares can be changed on short notice. Changes in schedules are more costly, and generally involve lead times of weeks or months. Thus, it seems reasonable to assume that a predatory airline can change its fares more quickly than its schedule, and that a rival can respond more quickly with fare changes of its own than by modifying its flight schedule. For purposes of analysis the four predation scenarios depicted in Table 1 will be considered.

In markets where fares are unregulated, Scenario A will apply only in the very short run — possibly a few hours. Once the rival has enough time to respond, Scenario B becomes relevant. Scenario C applies to the longer run when the predator can adjust its schedule, and Scenario D when the rival can respond in kind.

2.5 Existence and properties of equilibrium

Existence and uniqueness of competitive equilibrium in spatial markets have been the subject of intensive research over the years. Roughly speaking, several features of our model are conducive to existence of a unique equilibrium, including idiosyncratic preferences for airlines, quadratic schedule delay costs and price-elastic demand. But these are not enough to assure either existence or uniqueness. The sufficient conditions for existence derived by Caplin and Nalebuff (1991) are violated by our assumption that the distribution of departure time preferences is discrete rather than continuous. Bester's (1992) conditions for existence and uniqueness are also not satisfied. Resort to mixed strategies can restore equilibrium, but it seems doubtful whether mixed strategies are relevant to interfirm rivalry, particularly in airline markets where fares are quickly and easily adjusted.

Determining whether an equilibrium exists is further complicated when there are capacity constraints. Kohlberg (1983) and Rietveld and Rouwendal (1996) have shown that in location games with fixed prices, capacity constraints militate against existence of equilibrium. By contrast, Wauthy (1996) has demonstrated that in price games with fixed locations, capacity constraints can restore existence. Temporal peaking of demand is another factor that can cause nonexistence of equilibrium (Rietveld and Rouwendal, 1996). And if an equilibrium does exist, it may be asymmetric. For example, Tabuchi and Thisse (1995) show that with a triangular consumer density on a Hotelling line market, no symmetric duopoly location-price equilibrium exists. The only equilibria are asymmetric, with one firm located outside the market. Similarly, Ansari *et al.* (1994) obtain asymmetric equilibria when the density of consumers has a beta distribution.

A final complicating factor in our model is that a predatory airline's objective function is a weighted sum of its own profits and the rival's profit. To the best of our knowledge, neither the existence of equilibrium nor the characteristics of equilibrium if it exists have been investigated for such a game.

Let us now assume that a unique equilibrium to the two-stage schedule-fare game exists, and consider its properties. It is straightforward to show that flight times are homogeneous of degree zero in the parameters $\{a_1, a_2, t, \mu, V_0\}$. Fares and profits are homogeneous of degree one in the same parameters. If the costs of carrying passengers were included in the model, profits would also be homogeneous of degree zero in a_1, a_2 , and marginal passenger costs. Thus, the a_i parameters can be thought of as airline-specific systematic utility net of marginal costs.

A question of central interest in the paper is whether airlines prefer to space their flights out over the day, or to concentrate them at certain times. Spacing flights out has the

advantage that more prospective travelers can be offered convenient flight times. It also reduces "cannibalization" of business between sister flights. However, load factors can be increased by scheduling flights at times of peak demand. Borenstein and Netz (1991) refer to this as "natural crowding" of schedules.

Another question is whether airlines prefer to schedule their flights close to rival flights, or away from them. Two competing forces are at work. On the one hand, competition for market share encourages agglomeration, a tendency which is accentuated by natural crowding. On the other hand, distancing flights from rivals reduces the intensity of fare competition. Indeed, Martinez-Giralt and Neven (1988) and Bensaïd and de Palma (1994) have shown that two-product duopolists competing on a circular market may choose to locate their products at the same point in order to minimize price competition. Depending on the relative strengths of the opposing forces of attraction and repulsion, two types of equilibrium scheduling patterns can emerge. In one, rival flights are "interlaced". In a duopoly this would mean that Airline 1, say, operates the first morning flight, Airline 2 the next flight, followed by Airline 1's second flight, and so on throughout the day. The other scheduling pattern involves "segmentation", whereby each airline schedules its flights in a time interval or bank that does not overlap rivals' flights. Brander and Eaton (1984), Anderson (1985) and Bensaïd and de Palma (1994) have shown that both interlaced and segmented equilibria can exist in a given spatial market. Thus, location-price equilibria with multi-product firms need not be unique.

3 NONPREDATORY AND PREDATORY SCHEDULE-PRICE EQUILIBRIA

In this section we investigate the nature of nonpredatory and predatory location-price equilibria in an airline duopoly. Two abstract markets are considered. The first is a prototypical market with a single demand peak. Each airline schedules one or two flights per day. The main purpose of this example market is to explore the comparative static properties of schedule-price equilibria. The second market features a double demand peak that is more characteristic of airline markets. Each airline schedules three flights per day.

3.1 Market 1

Market 1 has a symmetric triangular population density function, as in Tabuchi and Thisse (1995). The distribution is approximated with 288 consumer mass points, spaced at five minute intervals. The density peaks between mass points 144 and 145 at two and a half minutes past noon (12:02:30). Peak density is three times the minimum density, at mass points 1 and 288.¹¹ The time step, Δx , between feasible flight times is also set at five minutes. The number of potential travelers is fixed at 1,000. Other base-case parameter values are $a_1 = a_2 = 0$, $t = 10$, $\mu = 25$, and $V_0 = -25$, measured in U.S. dollars.¹²

¹¹ In three dimensions the distribution looks like a ship's funnel, with a circular base and a raked profile.

¹² Adjusted for inflation the value of t is comparable to estimates for business travelers reported by Morrison and Winston (1985) and Norman and Strandenæs (1994). The value of μ is broadly consistent with

3.1.1 One flight each

Equilibria for the base-case parameter values when each airline schedules one flight per day are described in Row 1 of Table 2. Airlines schedule their flights symmetrically on either side of the demand peak.¹³ Each plane carries 69.3 people (D_1 and D_2 denote the airline's respective demands) at a fare of \$35.30, and earns a revenue of \$2,448.¹⁴ About 14% of the population of 1,000 individuals chooses to fly. The proportion is small because schedule delay costs are relatively high, and because only two flights are available to prospective travelers throughout the day. The equilibrium price elasticity of demand is -1.22, which is within the range of estimates commonly found.

Rows 2-7 of Table 2 illustrate how equilibrium is affected when either a key parameter value, or the distribution of consumers, is changed. When the schedule delay cost parameter, t , is halved (Row 2) flights are moved 20 minutes away from the peak. This happens because, with lower schedule delay costs, fare competition becomes more intense and its repulsive force outweighs the attraction of gaining market share. Fares drop only marginally, but demand rises appreciably because the generalized cost of travel is lower.

In Row 3 the scale parameter for idiosyncratic utility, μ , is quadrupled. Airlines reschedule their flights slightly closer to the peak.¹⁵ With the higher idiosyncratic utility, systematic differences in utility become relatively less important in determining travelers' choice of airline. This weakens fare competition, and encourages agglomeration. In Row 4, utility from the outside good is reduced. This makes traveling more attractive and increase competition between the airlines. As a result, flights are scheduled further apart, while fares, demand and profits rise.¹⁶

Row 5 introduces an asymmetry between the airlines by raising a_1 to \$25. Airline 1 reschedules its flight 40 minutes closer to the peak, while Airline 2 moves an hour further away. Airline 1 raises its fare and its profits nearly double. In Row 6, the demand distribution is made more peaked by reducing the minimum density to zero. This increases the incentive for agglomeration and flights are rescheduled closer to the peak. Fares change little, but demand and profits rise because, with a more concentrated population distribution, the average generalized cost of travel falls. Finally, in Row 7 the population

Morrison and Winston's (1989) estimate of the benefit per trip from a frequent flier program.

¹³ By contrast Tabuchi and Thisse (1995) find that no symmetric equilibrium exists with a triangular demand distribution. However, their model differs in that demand is price-inelastic and idiosyncratic utility is excluded.

¹⁴ The fare may seem low, but recall that the marginal cost of carrying passengers is set to zero and no flight capacity constraints are imposed.

¹⁵ Similar results are found in de Palma *et al.* (1985) and Neven (1986).

¹⁶ The slight asymmetry of the equilibrium (Airline 2's flight is five minutes closer to the peak) is attributable to imperfections in the algorithm.

distribution is made uniform. Without any incentive to agglomerate, airlines now schedule their flights twelve hours apart. Generalized costs rise, and demand and profits fall.

Table 2: Comparative statics properties of nonpredatory equilibrium: Market 1, $N_1 = N_2 = 1$.

Row	Case	x_1	x_2	p_1	p_2	D_1	D_2	Π_1	Π_2
1	Base	10:25	13:40	35.3	35.3	69.3	69.3	2448	2448
2	$t=5.0$	10.05	14:00	35.14	35.14	93	93	3266	3266
3	$\mu=100$	10:30	13:35	122.3	122.3	81.2	81.2	9929	9929
4	$V_0=-50$	10:10	13:50	43.51	43.51	105	105	4565	4586
5	$a_1=25$	11:05	14:40	43.63	35.32	111	64.8	4846	2287
6	Triangle	10:45	13:25	35.09	35.08	86.7	86.3	3045	3026
7	Uniform	6:00	18:00	35.32	35.32	53.6	53.6	1893	1893

Table 3 summarizes the predatory equilibria that result in Market 1 with the predation parameter set to $\delta=1$. For ease of comparison, the nonpredatory equilibrium is reproduced in the first row as Scenario NP. Variables that are fixed in each predation scenario are marked in bold face.

In predation Scenario A the predator (Airline 1) reduces its fare slightly, inflicting a minor loss on the rival of less than \$6/day. The predator accomplishes this at a cost to itself, shown by the ratio $\Delta\Pi_1/\Delta\Pi_2$ in the last column, that is only half as great.¹⁷ In Scenario B the rival responds by reducing its fare very slightly. Its own profits recover by only a few cents per day.¹⁸ In Scenario C, the predator reschedules its flight nearly two hours closer to the peak and drops its fare more sharply. Profits of both airlines now fall appreciably. Finally, in Scenario D the rival moves its flight away from the peak, further from the predator's.¹⁹ This weakens the impact of the predator's attack, and it responds by pulling its flight back.

¹⁷ Since the predator is at a profit maximum in the nonpredatory equilibrium, the loss of profit from changing fare slightly is, by the envelope theorem, second-order small in the neighborhood of the equilibrium.

¹⁸ Again this follows from the envelope theorem.

¹⁹ In Scenario D the algorithm does not converge to a location equilibrium, but enters a location cycle: $(x_{11}, x_{21}) = (11:55, 14:55) - (12:10, 14:55) - (12:10, 9:10) - (11:55, 9:10) \dots$. Airline 2 attempts to distance its flight from Airline 1's by scheduling it at the opposite half of the day, while Airline 1 follows in pursuit. To avoid this unrealistic outcome the algorithm was rerun with Airline 2 constrained to schedule its flight in the afternoon. This resulted in a smaller location cycle: $(12:05, 15:05) - (12:10, 15:05) - (12:10, 15:10) - (12:05, 15:10) \dots$. Fares and profits differ little across these four location pairs. The smallest gain from rescheduling a flight is for Airline 1 from $(12:05, 15:05)$ to $(12:10, 15:05)$. On this basis we chose $(12:05, 15:05)$ as the equilibrium.

Paradoxically, the predator's profit recovers to a level higher than in the nonpredatory equilibrium, even though its objective there was to maximize its current profits. This happens because aggressive behaviour by the predator leads, in equilibrium, to defensive behaviour by the prey that acts to the predator's advantage.²⁰

Table 3: Predatory equilibria: Market 1, $N_1 = N_2 = 1$, base-case parameters, $\delta = 1$.

Scenario	x_1	x_2	p_1	p_2	Π_1	Π_2	$\Delta\Pi_2$	$\frac{\Delta\Pi_1}{\Delta\Pi_2}$
NP	10:25	13:40	35.3	35.30	2448	2448	—	—
A	10:25	13:40	33.87	35.30	2445	2442	-5.6	0.50
B	10:25	13:40	33.86	35.29	2445	2442	-5.6	0.50
C	12:20	13:40	28.41	33.28	2167	2019	-428	0.66
D	12:05	15:05	33.68	35.16	2534	2206	-242	-0.36

To test the sensitivity of the results, predatory equilibria were recomputed with $\delta = 0.5$. Qualitatively the same pattern obtains for Scenarios A-C as in Table 3, although as expected Airline 1's predatory efforts are muted. Scenario D differs in that, rather than pulling back when the rival moves away, Airline 1 advances its flight further from 11:05 to 11:20. This leads to a further reduction in the rival's profits.

The impact of predatory behaviour in Market 1 may appear rather modest. But if operating costs were netted out, the proportional effects on profits would be much greater. And the effects would be larger with a larger δ . As noted above, the value of this parameter is determined by a number of route- and airline-specific factors.

In the base case nonpredatory equilibrium, flights carry 69 passengers each. To examine the effects of capacity constraints it was assumed that planes can only carry 50 passengers.

Table 4: Equilibria for plane capacity 50: Market 1, $N_1 = N_2 = 1$, base-case parameters, $\delta = 1$.

Scenario	x_1	x_2	p_1	p_2	Π_1	Π_2	$\Delta\Pi_2$	$\Delta\Pi_1/\Delta\Pi_2$
NP	10:40	13:35	46.69	46.4	2334	2321	—	—
C	12:00	13:35	44.92	43.6	2246	2180	-141	0.62
D	12:05	15:05	47.86	43.7	2393	2184	-137	-0.43

²⁰ More precisely, the change in the predator's objective function shifts its scheduling reaction curve. For a general discussion of this effect see Bulow *et al.* (1985).

The first row of Table 4 depicts the nonpredatory equilibrium for this game. Because excess demand is unprofitable,²¹ airlines raise their fares above the equilibrium fares that obtain with no capacity constraints until demand is reduced to capacity. They also reschedule their flights slightly closer to the peak (compare Table 2). This happens because capacity constraints soften fare competition, so that at the uncapacitated equilibrium locations the attraction of locating closer to peak demand outweighs the repulsive force of greater fare competition.

In all four of the predation scenarios capacity constraints bind. Predation by cutting fares alone is completely ineffective and so equilibria for Scenarios A and B are not reported. In Scenario C the predator reschedules its flight to noon, closer to the prey's flight. Though the predator's flight is now at the demand peak, both airlines have to cut fares to keep their planes full. The reason for this is that, being closer together, the two flights are jointly less attractive to consumers. The predator inflicts on its rival a profit reduction of \$141/day (6.0% of base-case profits) at a cost to itself of \$88/day. Once the prey is able to react (Scenario D) it reschedules its flight 90 minutes later. This does little to alleviate its losses, and the predator ends up better off than as a nonpredator. Thus, just as when capacity constraints are absent, it is possible for predation to raise current profits as well as expected future profits.

3.1.2 Two flights each

Equilibria when each airline operates two flights are shown in Table 5. In the nonpredatory equilibrium, rival flights are interlaced. Each airline schedules one flight in the morning and one in the afternoon. "Peak period" flights (those near noon) carry more passengers (65), than "off-peak" flights (57). But fares are almost the same because the elasticity of demand depends only on the shape of the consumer distribution and not on the density.

The pattern of predatory behaviour in Scenarios A and B is similar to the pattern when airlines have one flight each. In Scenario C, the predator reschedules both its flights much closer to the prey's flights. This inflicts a heavy loss in profits for both airlines. In Scenario D, the prey moves its flights away from the predator's. The predator responds by partially backing off its schedule attack, and the prey recovers much of its profit loss. The predator's profits recover too, but unlike the case with one flight each *II*, remains below the nonpredatory equilibrium level.

²¹ Boyer and Moreaux (1988, 1989) have shown that in a Stackelberg duopoly game the leader can profit by rationing its consumers because this inflates the follower's demand curve and induces it to raise its price. Boyer and Moreaux argue that bargain-price airlines may behave in this way to curb competition from other airlines. Such behaviour is not profitable in our model, where airlines move simultaneously. Furthermore, because rationing boosts profits for the follower more than for the leader, rationing would not be desirable for a predator that is trying to damage its rival.

Table 5: Equilibria: Market 1, $N_1 = N_2 = 2$, base-case parameters, $\delta = 1$.

	x_{11}, x_{12}	x_{21}, x_{22}	p_{11}, p_{12}	p_{21}, p_{22}	Π_1	Π_2	$\Delta\Pi_2$	$\Pi_1/\Delta\Pi$
NP	7:30,13:15	10:40,16:25	35.30,35.00	34.99,35.30	4277	4285	—	—
A	7:30,13:15	10:40,16:25	33.74,31.02	34.99,35.30	4253	4237	-47	0.51
B	7:30,13:15	10:40,16:25	33.73,31.02	34.92,35.28	4253	4237	-47	0.52
C	10:05,15:00	10:40,16:25	25.50,28.76	32.05,33.46	3694	3533	-752	0.78
D	9:20,13:55	11:35,17:15	31.69,30.75	34.29,35.34	4187	4013	-272	0.33

3.2 Market 2

Market 2 differs from Market 1 in featuring a bimodal distribution of demand from Miller (1972); see Figure 1. (Circles in Figure 1 represent flights in the nonpredatory equilibrium, discussed below.) The first peak corresponds to early morning outbound business trips, and the second to evening return business trips.²² Each airline is assumed to operate three flights per day. To limit computation time²³ the number of consumer mass points was reduced from 288 to 96, and the time interval between feasible flight times was correspondingly increased from 5 to 15 minutes. Other parameter values are the same as for Market 1.

The nonpredatory equilibrium is described in Row NP of Table 6. In Figure 1, flights of Airline 1 are shown by solid circles and flights of Airline 2 by hollow circles. As in Market 1 with $N_1 = N_2 = 2$, rival flights are interlaced. Morning flights of each airline are paired on either side of the morning peak. Similarly, evening flights are paired near the evening peak. Midday flights are further apart because the time period between them has a trough in the density function, giving airlines little incentive to locate there.²⁴

The pattern of predatory behaviour is broadly similar to that in Market 1. In Scenario A, the predator cuts its traffic-weighted average fare, \bar{p}_1 , by 19% to \$27.79. This reduces the

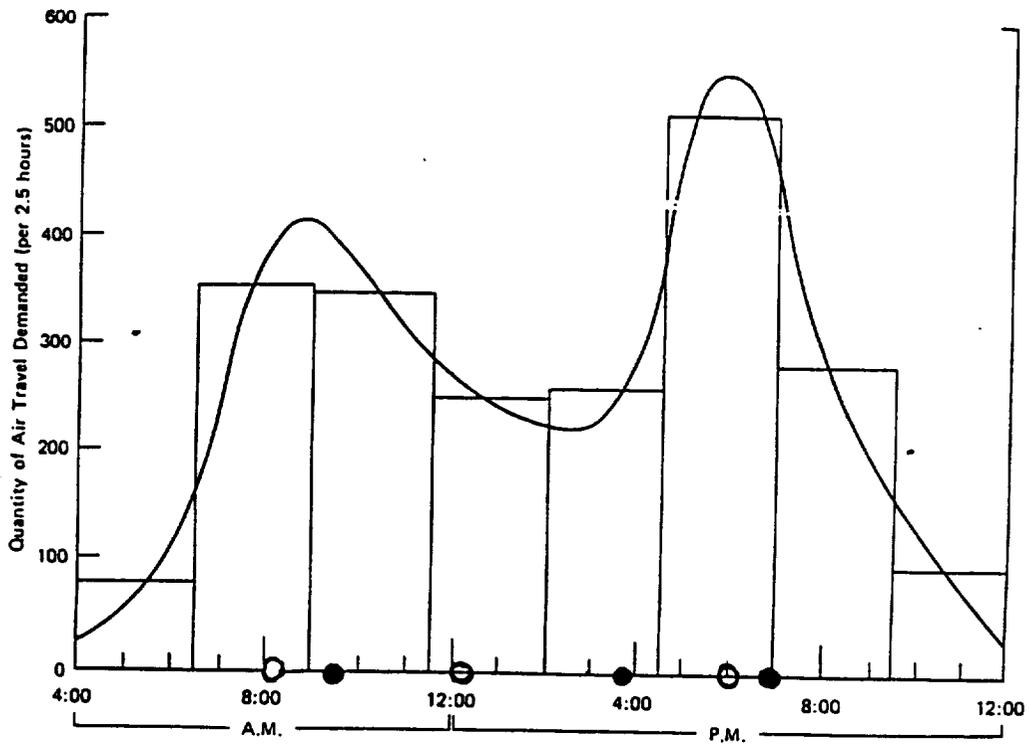
²² The precise shape of the distribution will depend on the route. For example, preferred departure times tend to be more concentrated on routes where travel times are long. Shape also varies with the relative importance of business travel.

²³ Computation time for the equilibria described in Rows NP and D of Table 6 below ranged from 2 to 2 ½ hours on a Cyrix 166 PC with 32 megabytes of RAM. Computation time is roughly proportional to the product of the number of consumer masses, K , and the number of feasible departure times, $T/\Delta x$.

²⁴ The comparative statics of equilibrium are similar to those of Market 1. For example, raising μ from 25 to 50 causes all three pairs of rival flights to cluster. Both morning flights end up being scheduled at 8:45.

prey's profit by \$354 (5%). The predator's sacrifice of profits is half as great. The prey responds in Scenario B with a small fare cut.²⁵ In Scenario C, the predator reschedules each of its flights closer to the rival's flight with which it is "paired", and the loss in prey's profits grows to 13%. Finally, in Scenario D the prey reschedules its flights, although only its midday flight changes much. The predator's evening flight ends up departing before the rival's evening flight, and the arrangement of flights is no longer interlaced.

Figure 1: Departure time preferences for Market 2



The effects of capacity constraints on equilibrium are examined in the same way as for Market 1 by imposing a limit of 50 passengers per flight. Again, capacity constraints bind in all predation scenarios so that price predation alone is ineffective. Comparing Table 7 with Table 6 it is evident that equilibrium schedules are similar to those with no capacity constraints. But fares rise appreciably to eliminate excess demand. And even predatory

²⁵ The prey's profits fall (by \$1) because the predator's average fare falls marginally from \$27.79 to \$27.77.

Table 6: Nonpredatory and predatory equilibria: Market 2, $N_1 = N_2=3$, $\delta=1$.

	x_{11}	x_{12}	x_{13}	x_{21}	x_{22}	x_{23}	\bar{p}_1	\bar{p}_2	Π_1	Π_2	$\Delta\Pi_1$	$\frac{\Delta\Pi_1}{\Delta\Pi_2}$
NP	9:30	15:45	19:00	8:15	12:15	18:00	34.2	34.3	6782	6962	—	—
A	9:30	15:45	19:00	8:15	12:15	18:00	27.8	34.3	6603	6608	-354	0.51
B	9:30	15:45	19:00	8:15	12:15	18:00	27.8	33.9	6580	6607	-355	0.57
C	8:45	13:00	18:15	8:15	12:15	18:00	25.7	32.6	6317	6063	-899	0.52
D	8:45	12:30	18:00	8:00	11:15	18:15	26.1	32.9	6382	6027	-935	0.43

Table 7: Equilibria for plane capacity 50: Market 2, $N_1 = N_2=3$, $\delta=1$.

	x_{11}	x_{12}	x_{13}	x_{21}	x_{22}	x_{23}	\bar{p}_1	\bar{p}_2	Π_1	Π_2	$\Delta\Pi_1$	$\frac{\Delta\Pi_1}{\Delta\Pi_2}$
N P	9:30	16:15	19:15	8:30	12:30	18:00	46.2	46.1	6937	6912	—	—
C	9:15	16:30	19:15	8:30	12:30	18:00	46.2	46	6930	6892	-20	0.32
D	8:30	12:00	18:00	9:15	16:15	19:15	45.9	46.1	6886	6914	2	-24

schedule adjustments are relatively ineffective. Indeed, in Scenario D the prey ends up marginally better off than in the nonpredatory equilibrium, while the predator ends up worse off! Once again this illustrates how changes in a firm's objective function induce changes in its reaction function(s) that can have counterintuitive effects on the resulting equilibrium.

4 CONCLUDING REMARKS

This paper has explored the nature of schedule and fare competition in an isolated city-pair market served by two airlines. Airlines play a noncooperative two-stage game: choosing flight times in Stage One and fares in Stage Two. Numbers of flights and aircraft capacity are treated as given. In the nonstrategic (nonpredatory) variant of the game, each airline maximizes its current profits. In the predatory version one airline, the predator, attempts to maximize its expected long-run profits by maximizing its current profits minus some multiple of the rival's profits.

Equilibria for both types of game are computed numerically using a two-stage tatonnement procedure. Depending on the characteristics of the market and parameter values, an equilibrium may or may not exist. If it exists, equilibrium may not be unique and may not be symmetric. In most, but not all, of the simulations that have been undertaken equilibria do exist. And no case of multiple equilibria has been encountered.

Equilibria were computed for two hypothetical markets, one with a single demand peak and one with a double demand peak. Nonpredatory equilibria are characterized by interlacing of rival flights, and moderate concentration of flights near times of peak demand.

Four predation scenarios were considered. In Scenarios A and B, the predator can change its fares but not its flight schedule, while in Scenarios C and D, the predator can change both its fares and its schedule. Predatory fare cutting alone is found to be relatively ineffective in inflicting damage on the rival, whether or not the rival can respond. Indeed, cutting fares is futile if flights are capacitated. Predatory rescheduling of flights closer to a rival's flight has greater potential for inflicting substantial losses. The extent of damage depends on whether flights are capacitated, and whether the prey can respond with schedule changes of its own. When the prey can respond its profits sometimes recover, and sometimes drop further. Similarly, the predator's profits can rise or fall. Thus, the effects of predation can be varied and sometimes counterintuitive.

There are several directions in which the analysis of the paper could be extended.

1. Demand is assumed to be stationary from day to day, so that a given flight is always capacitated or always uncapacitated. In practice demand for a flight fluctuates systematically by day of week and by season. Demand also fluctuates unpredictably. Thus, a flight can be full on some days and relatively empty on other days. The uncapacitated and capacitated equilibria computed here are polar extremes that may or may not bracket "reality". The model could be extended, at the cost of increased computation time, to allow for both predictable and unpredictable fluctuations, perhaps following the procedure of Powell and Winston (1983).
2. Prospective travelers are assumed to be identical in terms of their aversion to schedule delay and their sensitivity to fares. An obvious extension would be to introduce market segments. One possibility, as in Norman and Strandenes (1994), would be to distinguish between business and tourist class.
3. In the two hypothetical markets considered, airlines scheduled at most three flights. Yet some routes, such as Los Angeles — San Francisco, are served by dozens of flights. With more flights the average interval between rival flights falls, and fare competition becomes more intense. It remains to be seen whether interlacing persists as the equilibrium configuration, or whether segmentation develops. Predatory behaviour could also take the form of "bracketing", whereby the predator squeezes a rival's flight by scheduling two flights nearby, one earlier and one later.
4. Finally, attention has been limited to a single market in isolation. Yet many routes are interconnected through hub-and-spoke networks. Interconnection imposes constraints on the timing of flights. For example, Borenstein and Netz (1991) report that flight schedules tend to be more concentrated on routes with fewer connecting passengers, as well as on longer routes — which are less likely to involve connections. Thus, the analysis could be extended to airline networks to see how this affects departure time competition and crowding. The work of Encaoua *et al.* (1996) is a step in this direction.

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**A MODEL OF AIR TRANSPORT DUOPOLY
IN PRICE AND SERVICE QUALITY**

(preliminary version)

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The liberalization process of the air transport industry in Europe, which officially ended in April 1997, echoes the American Air Deregulation Act (ADA) that was passed some twenty years earlier, in 1978. Quite logically, the European observers try to infer from the American experience what the evolution of the industry can be on their own continent. In particular, one of the most spectacular consequences of the ADA was the continent-wide development of hub-and-spoke systems, in which all passengers, whatever their origins and destinations, are channelled to a hub airport, where they find convenient intraline connections to reach their final destination. Such networks were initially developed by the major air carriers to minimize their operating costs (owing to the flow consolidation on the spokes); hubbing also gave them the opportunity to monopolize the hub airport's resources (by the concentration of incoming and outgoing flights on a short time span) and is therefore an interesting tool to lower the contestability of the hub markets.

Although the American experience has been extensively analyzed, very little can be learnt to help forecast the future of the European flag carriers' networks. In this purpose, a two-stage duopoly model is proposed in this paper, which considers both prices and network patterns as endogenous variables. This model structure is suggested by the American experience – that made it clear that a carrier's network can act as a strategic tool just like other more classic device, such as marketing or prices – and by the industry practices themselves: the two-period structure is meant to more or less reproduce the fact that at every season for the next one the carriers choose the slots they will need at the airports they want to serve, publish their timetables, while their prices generally keep on varying until the last ticket is sold.

The paper is organized as follows: section I presents the model, which is then solved in section II; the empirical test of the model is conducted in section III on American data.

1. PRESENTATION OF THE DUOPOLY MODEL

The model illustrates the situation where two airlines compete (non-cooperatively) first in a variable that defines their network structure and then on the price of their product. The first period decision concerns the quality of service of their flights, that can be either connecting or direct. Note that only connecting or direct flights will be considered (no one-stop or multi-stop flights with no change of aircraft).

More specifically, two airlines A and B compete to serve the same (given) set of n cities. The competitive game between them is the following two-stage game with imperfect and complete information:

First stage: the carriers simultaneously and independently choose their network pattern. On each market with origin i and destination j , carrier A (respectively B) chooses PAT_{ij}^A (resp. PAT_{ij}^B), with value 1 if A (B) proposes a direct flight on market i - j , to 0 otherwise.

It should be noted that the airlines' choice of PAT_{ij}^A and PAT_{ij}^B results from a trade-off between their market share and their cost level: the more the network is centralized (many

connecting flights), the lower the costs (fewer planes to operated, higher load rates) but the higher the risk of losing market share if the rival offers direct flights¹.

Second stage: Each carrier learn about their rival's network pattern choice, and then simultaneously and independently choose their prices p_{ij}^A and p_{ij}^B , $\forall i, j = 1..n, i \neq j$.

Each carrier chooses its price and pattern variables to maximize its profit level.

1.1. General Hypotheses

The two airlines are symmetric and have the same profit function. In the case of non direct flights between two cities, the following hypotheses are made:

- non direct flights are one connection flights only;
- when for a given carrier flights are not direct, passengers can only connect on one airport among the n s. This airport, that will be noted H^A and H^B according to the carrier, is supposed to be linked to the other cities with direct flights only: $PAT_{iH^A}^A = PAT_{H^A i}^A = 1 \forall i \neq H^A$, and $PAT_{iH^B}^B = PAT_{H^B i}^B = 1 \forall i \neq H^B$. This airport is obviously the potential hub of the carrier.
- the passengers only have online connections (no interlining).
- each carrier offers only one routing per O-D market.

Concerning the demand: O-D traffics are exogenous and non null, equal to Q_{ij} , $i, j = 1..n, i \neq j$. All demand is served by the two carriers. The O-D flows are symmetric and there is no distinction between passenger classes (e.g. business and tourism).

Concerning the carriers' fleets: both carriers operate the same type of aircraft, the number and type of which being given. There is no constraint from the fleet on the routing quality decision of the airline and it is also supposed that the immobilization cost of the aircraft and the airport utilization cost are null. There is no aircraft capacity constraints (aircraft are supposed to never be 100 % full).

1.2. Demand and Yield Functions

The carrier's yield is an additive function of the yield obtained on each O-D market, which is of course equal to the price paid by every traveler on the market times the number of passengers carried. As the whole demand is served by the two carriers, the number of passengers on O-D market $i-j$ can be written as the total demand on $i-j$, Q_{ij} , times A (B)'s market share on $i-j$, MS_{ij}^A (or MS_{ij}^B) with $MS_{ij}^A + MS_{ij}^B = 1$ and $0 \leq MS_{ij}^A, MS_{ij}^B \leq 1$. Furthermore, to ensure that the price paid by the traveller will depend on the O-D market

¹ Under the assumption that the travelers prefer direct to connecting flights, *ceteris paribus*.

length, it will be supposed that the price variable, the value of which is chosen by the carriers at the second stage of the game, is the unit price per kilometer. Consequently, carrier A's yield function can be written as²:

$$\sum_{i=1}^n \sum_{\substack{j=1 \\ j \neq i}}^n Q_{ij} \cdot MS_{ij}^A \cdot p_{ij}^A \cdot d_{ij} \quad (1)$$

where d_{ij} is the great-circle distance (in km) between i and j .

The market share on market i - j is written as a logit function of the strategic variables, p_{ij} and PAT_{ij} :

$$MS_{ij}^A(p_{ij}^A, p_{ij}^B, PAT_{ij}^A, PAT_{ij}^B) = \frac{\exp(a + b.p_{ij}^A + c.PAT_{ij}^A)}{\exp(a + b.p_{ij}^A + c.PAT_{ij}^A) + \exp(a + b.p_{ij}^B + c.PAT_{ij}^B)} \quad (2)$$

where $b < 0$, $c > 0$.

The travelers are supposed to prefer (*ceteris paribus*) direct to connecting flights and low prices: therefore parameter c is positive and b is negative.

1.3. Cost function

The operating cost function is equal to the sum of the operating costs born by the carrier on each segment served by a (direct) flight. Following Pavaux (1984), the latter is a function of the distance flown and of the number of passengers aboard:

$$C_{ij} = \alpha + \beta.d_{ij} + \gamma.(\text{number of passengers}), \text{ with } \alpha, \beta, \gamma > 0$$

The two first terms ($\alpha + \beta.d_{ij}$) can be interpreted as the cost to bear for installing capacity K on link i - j (where K is the seat capacity of an aircraft), born at the first stage of the game, while the last term, $\gamma.(\text{number of passengers})$, can be interpreted as a production cost, born at the second stage of the game. In other respects, the independence of the first terms from the production cost ensures that the cost function exhibits both link economies of scale to the number of passengers (economies of density) and economies of scope, as it is usually the case in air transport.

The number of passengers on board, hence the cost born on a segment, depends on the network pattern. For carrier A (for example), it equals to:

$$\sum_k Q_{ik} MS_{ik}^A (1 - PAT_{ik}^A) + Q_{iH^A} MS_{iH^A}^A \text{ on link } iH^A, i \neq H^A \quad (3a)$$

$$\text{and } PAT_{ij}^A \cdot Q_{ij} \cdot MS_{ij}^A \text{ on link } ij, i, j \neq H^A \quad (3b)$$

² To avoid redundancy, given the symmetry between the two airlines, only carrier A's equations will be mentioned, except when carrier B's are of interest in themselves.

Carrier A's total cost is therefore equal to:

$$\begin{aligned}
C^A = & \sum_{i \neq H^A} \alpha + \beta \cdot d_{iH^A} + \gamma \cdot \left(\sum_k Q_{ik} \cdot MS_{ik}^A \cdot (1 - PAT_{ik}^A) + Q_{iH^A} \cdot MS_{iH^A}^A \right) \\
& + \sum_{j \neq H^A} \alpha + \beta \cdot d_{H^A j} + \gamma \cdot \left(\sum_l Q_{lj} \cdot MS_{lj}^A \cdot (1 - PAT_{lj}^A) + Q_{H^A j} \cdot MS_{H^A j}^A \right) \\
& + \sum_{i \neq H^A} \sum_{j \neq H^A} PAT_{ij}^A \cdot (\alpha + \beta \cdot d_{ij} + \gamma \cdot Q_{ij} \cdot MS_{ij}^A)
\end{aligned} \quad (4)$$

Finally, carrier A's maximization program is the following:

$$\text{Max}_{p_{ij}^A, PAT_{ij}^A, i, j=1..n} \pi^A = \left[\begin{aligned} & \sum_{i=1}^n \sum_{j=1}^n Q_{ij} \cdot MS_{ij}^A \cdot p_{ij}^A \cdot d_{ij} - \sum_{i \neq H^A} \alpha + \beta \cdot d_{iH^A} + \gamma \cdot \left(\sum_k Q_{ik} \cdot MS_{ik}^A \cdot (1 - PAT_{ik}^A) + Q_{iH^A} \cdot MS_{iH^A}^A \right) \\ & - \sum_{j \neq H^A} \alpha + \beta \cdot d_{H^A j} + \gamma \cdot \left(\sum_l Q_{lj} \cdot MS_{lj}^A \cdot (1 - PAT_{lj}^A) + Q_{H^A j} \cdot MS_{H^A j}^A \right) \\ & - \sum_{i \neq H^A} \sum_{j \neq H^A} PAT_{ij}^A \cdot (\alpha + \beta \cdot d_{ij} + \gamma \cdot Q_{ij} \cdot MS_{ij}^A) \end{aligned} \right] \quad (5)$$

with $\forall i, j = 1..n, i \neq j$:

$$(PAT_{ij}^A, PAT_{ij}^B) \in \{0, 1\}^2$$

$$(p_{ij}^A, p_{ij}^B) \in \mathbb{R}_+^2$$

2. PRICE AND PATTERN EQUILIBRIA

This two-stage game is classically solved by solving it first for the second stage variable (price): we obtain the expression of the equilibrium prices where the routing quality variable enters as a parameter. Then the solving of the first stage game produces the equilibrium values of the PAT variables, hence the equilibrium of the whole game.

The second sub-game is solved by simply deriving the profit function, since it can be shown to be concave in the price variable at least for pertinent values of this variable. Consequently, so long as each carrier's market share is non null, the equilibrium price is given by:

$$p_{ij}^{A*} = \frac{\gamma \cdot (2 - PAT_{ij}^A)}{d_{ij}} - \frac{1}{b \cdot (1 - MS_{ij}^A(p_{ij}^{A*}))} \quad (6)$$

where the star exponent denotes equilibrium values.

The case when $MS_{ij}^A = 0$ (or $MS_{ij}^B = 0$) is a limit case, since the market share can only be equal to zero when the price become infinite ($MS_{ij}^A \rightarrow 0$ when $p_{ij}^A \rightarrow +\infty$). The price variable will therefore be supposed to take only finite positive values.

As the PAT variable can only take two values, the corresponding sub-game will be solved using the normal form of the game, where the payoffs are the incremental profits (which is different from the profit as defined above). The incremental profit obtained on a market is the difference between the yield obtained on it and the incremental cost, which is the part of the operating cost only attributable to the market under consideration. This notion

avoids double counts of joint costs. The hypothesis according to which iH^A or $H^A i$ (iH^B or $H^B i$) -type markets are served by direct flights only makes it possible to write the incremental cost (or profit) on market $i-j$: for any connecting flight on this market, the cost of installing capacities on segment iH^A (for example) can be attributed to O-D market iH^A , even when it is a joint cost; it is then possible to attribute to each market the part of the cost that varies with the number of passengers carried. More precisely, the incremental profit obtained by carrier A on return O-D market $i-j$, $i,j \neq H^A$ is noted π_{ij}^A and equals:

$$\pi_{ij}^A = 2 \cdot \left\{ Q_{ij} MS_{ij}^A \cdot (p_{ij}^A d_{ij} - \gamma) - (\alpha + \beta d_{ij}) \right\} \quad \text{when } i-j \text{ is served direct (PAT}_{ij}^A=1) \quad (7a)$$

or

$$\pi_{ij}^A = 2 \cdot Q_{ij} MS_{ij}^A \cdot (p_{ij}^A d_{ij} - 2\gamma) \quad \text{when } i-j \text{ is served via } H^A \text{ (PAT}_{ij}^A=0) \quad (7b)$$

2.1. Solving the PAT sub-game

As the solving of the price sub-game is quite straight-forward, we shall pass directly to the solving of the routing sub-game; details can be found in Molin (1997). As noted above, the first stage game is solved using the normal form of the game with incremental profits as pay-offs (Cf. table 1). The values of the incremental profits in table 1's cells were computed for every possible pattern values and given the equilibrium prices as produced by the solving of the second period sub-game.

The analysis that follows only deals with $i-j$ type markets ($i,j \neq H^A, H^B$), which does not involve hubs, since by hypothesis the markets from or to a hub are served direct by the hubbing carrier. The $i-H^A$ and $i-H^B$ cases appear as degenerated cases of the general sub-game applying to the $i-j$ markets; consequently the solving of the game is focusing only on the $i-j$ markets, as the results obtained on $i-j$ include those that can be obtained on the $i-H^A$ and $i-H^B$ markets. In practical terms, considering the $i-H^A$ market (for example) amounts to restricting table 1 to a one line (since by hypothesis there is no case when $PAT_{iH^A}^A=0$) - two column table.

Table 1 : Normal form of the routing quality game (symmetric duopoly)

		Carrier B	
		i-j direct (PAT _{ij} ^B = 1)	i-j via H ^B (PAT _{ij} ^B = 0)
Carrier A	i-j direct (PAT _{ij} ^A = 1)	$\left(\begin{array}{l} -\frac{2Q_{ij}d_{ij}}{b} - 2(\alpha + \beta d_{ij}) = X_{ij}; \\ -\frac{2Q_{ij}d_{ij}}{b} - 2(\alpha + \beta d_{ij}) = X_{ij} \end{array} \right)$	$\left(\begin{array}{l} -\frac{2Q_{ij}d_{ij}}{b} \cdot \frac{MS_{ij}^A}{MS_{ij}^B} - 2(\alpha + \beta d_{ij}) = Y_{ij}; \\ -\frac{2Q_{ij}d_{ij}}{b} \cdot \frac{MS_{ij}^B}{MS_{ij}^A} = Z_{ij} \end{array} \right)$ <p>where PAT_{ij}^A = 1 = 1 - PAT_{ij}^B in MS_{ij}^A and MS_{ij}^B (MS_{ij}^B < 1/2 < MS_{ij}^A).</p>
	i-j via H ^A (PAT _{ij} ^A = 0)	$\left(\begin{array}{l} -\frac{2Q_{ij}d_{ij}}{b} \cdot \frac{MS_{ij}^A}{MS_{ij}^B} = Z_{ij}; \\ -\frac{2Q_{ij}d_{ij}}{b} \cdot \frac{MS_{ij}^B}{MS_{ij}^A} - 2(\alpha + \beta d_{ij}) = Y_{ij} \end{array} \right)$ <p>where PAT_{ij}^A = 0 = 1 - PAT_{ij}^B in MS_{ij}^A and MS_{ij}^B (MS_{ij}^A < 1/2 < MS_{ij}^B).</p>	$\left(\begin{array}{l} -\frac{2Q_{ij}d_{ij}}{b} = X'_{ij}; \\ -\frac{2Q_{ij}d_{ij}}{b} = X'_{ij} \end{array} \right)$

The equilibrium is characterised by various values for (PAT_{ij}^A, PAT_{ij}^B), according to the values obtained for the incremental profit. Omitting ij indices, we know that: X < Y, X < X' and Z < X' but the order between Y and Z, Y and X', X and Z is unclear. There are three possible cases³:

(1) Y < X'

which produces one Nash equilibrium in pure strategies: (PAT_{ij}^A = PAT_{ij}^B = 0);

Each carrier will prefer to offer connecting service on market i-j rather than get a larger yield from direct service (the larger yield cannot compensate the additional cost because of direct service). The *cost factor* is the driving force of each carrier's pattern decision.

(2) Z < X

which produces one Nash equilibrium in pure strategies: (PAT_{ij}^A = 1; PAT_{ij}^B = 1).

Each carrier prefers offering direct service on market i-j rather than benefiting from cost savings owing to connecting service (the cost savings are not high enough to compensate

3. The case when Z < X < Y < X' is not relevant here since it can be shown that (Z < X) ⇒ (X' < Y).

the lower yield stemming from connecting flights). The *yield factor* is the driving force of each carrier's pattern decision.

(3) $X < Z$ and $X' < Y$

This twofold condition leads to two Nash equilibria in pure strategies: $(PAT_{ij}^A = 0; PAT_{ij}^B = 1)$ and $(PAT_{ij}^A = 1; PAT_{ij}^B = 0)$; there is one Nash equilibrium in mixed strategies, where each carrier "plays" $PAT_{ij} = 1$ with probability (inferior to $\frac{1}{2}$):

$$\frac{Y - X'}{Z - X + Y - X'} = \frac{1}{2} + \frac{\alpha + \beta d_{ij}}{2Q_{ij}d_{ij} \left(1 - \frac{MS_{ij}^B \binom{0}{1}}{MS_{ij}^A \binom{0}{1}} \right)} \quad (\text{vector } \binom{0}{1} \text{ indicates the values taken by}$$

PAT_{ij}^A and PAT_{ij}^B in the computation of the corresponding market shares)

In this case, carrier A and B's (expected) incremental profits on market i-j equal:

$$\pi_{ij} = \frac{X' - Y}{X - Z + X' - Y} X + \frac{X - Z}{X - Z + X' - Y} Y = \frac{2 \cdot (\alpha + \beta d_{ij})}{\frac{MS_{ij}^A \binom{1}{0} - MS_{ij}^B \binom{1}{0}}{MS_{ij}^B \binom{1}{0}}} \quad (8)$$

Each carrier prefers *avoiding head-on competition with its rival*, which explains its own indifference between the two possible patterns. Its strategy can be viewed as an "*avoiding strategy*" and is reminiscent of the maximal differentiation strategy in the duopoly with product differentiation, to avoid direct price competition.

2.2. Synthetic Representation of the Network Pattern Solutions

Each of the three equilibrium conditions is expressed as a function of the cost, demand and distance parameters and variables. The study of these functions produces reduced forms that can easily be represented on a graph.

Let f and g be as follows (omitting the ij indices):

$$f = \frac{X' - Y}{2} = \alpha + \beta d + \frac{Q_d}{b} \frac{MS^A \binom{1}{0} - MS^B \binom{1}{0}}{MS^B \binom{1}{0}} \quad (9)$$

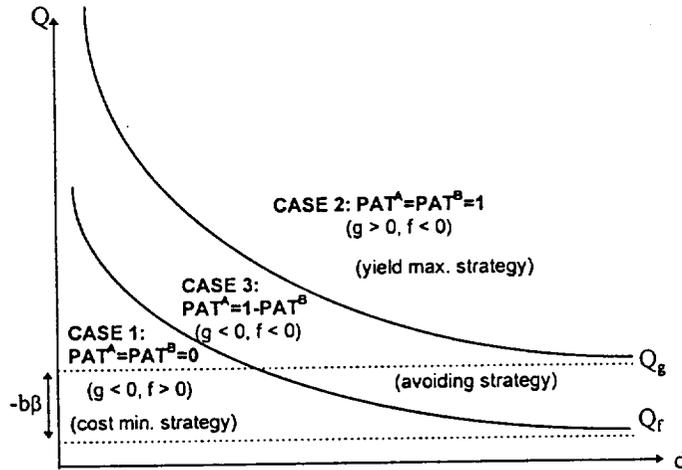
and:

$$g = \frac{X - Z}{2} = -\frac{Q_d}{b} \frac{MS^A \binom{1}{0} - MS^B \binom{1}{0}}{MS^A \binom{1}{0}} - (\alpha + \beta d) = -f + \frac{Q_d}{b} \frac{\{MS^A \binom{1}{0} - MS^B \binom{1}{0}\}^2}{MS^A \binom{1}{0} \cdot MS^B \binom{1}{0}} \quad (10)$$

The conditions for Case 1 ($PAT^A = PAT^B = 0$) are met when f is positive; the conditions for Case 2 ($PAT^A = PAT^B = 1$) are met when g is positive. Finally, when both f and g are negative, the equilibrium situation corresponds to Case 3 ($PAT^A = 1 - PAT^B$).

When the structural parameters (type of aircraft and demand split function) are given, the emergence of one of the three possible Nash equilibria depends on the value of two variables: total O-D traffic, Q , and O-D distance, d . In order to determine the portions of the (Q,d) plane corresponding to each Nash equilibrium, we define the functions Q_f and Q_g of d , such that $f(Q_f, d) \equiv 0$ and $g(Q_g, d) \equiv 0$. As Q_f is always inferior to Q_g , the zone where $f > 0$ is always below the Q_f curve, while the portion of the plane where $g > 0$ is always above the Q_g curve. Easy but laborious calculations (Cf. Molin, 1997) lead to the following graph (figure 1):

Figure 1: Synthetic representation of the equilibrium pattern strategies



It should be noted that according to intuition, for given O-D distances, the higher the O-D traffic levels, the more liable a carrier is to offer direct flights rather than connecting flights. However, for given O-D traffic levels, the shorter the distance, the more the carriers tend to offer connecting services, which is counter-intuitive. This is due to the relative variation with distance of prices and market shares when $PAT^A = PAT^B = 0$ compared to when $PAT^A = 1 = 1 - PAT^B$. When distance decreases, the increase in carrier A's uiled compesnates the decrease in its market share all the more when it chooses $PAT^A = 0$ than when it chooses $PAT^A = 1$ as its rival chooses $PAT^B = 0$. See Molin (1997) for more explanations.

Figure 1 allows a discussion on the market conditions for such and such air network patterns at equilibrium, and more especially hub-and-spoke networks.

2.3. Application: Conditions for Hub-and-Spoke Networks at Equilibrium

In this paragraph, we analyse the conditions on total O-D passenger traffic levels (Q) and O-D length (d) to have both carriers choose the hubbing network pattern at equilibrium. In accordance with the European air transport industry, we only consider the case when the potential hubs, H^A and H^B , are located on different airports. For the sake of simplicity, it will be supposed that carrier A's hub, H^A , corresponds to point n and carrier B's hub, H^B , to point $n-1$ ($H^A \neq H^B$).

Generalized hub-and-spoke networks appear at equilibrium when (with $H^A \neq H^B$):

on markets $i-j$, $i, j \neq H^A, H^B$, we have $PAT_{H^A H^B}^{A*} = PAT_{H^A H^B}^{B*} = 0$ (Case 1),

on markets $i-H^A$, $i \neq H^A, H^B$, we have $PAT_{iH^A}^{A*} = 1 = 1 - PAT_{iH^B}^{B*}$ (degenerated case of Case 3),

on markets $i-H^B$, $i \neq H^A, H^B$, we have $PAT_{iH^B}^{A*} = 0 = 1 - PAT_{iH^B}^{B*}$ (degenerated case of Case 3),

on market $H^A - H^B$, we have $PAT_{H^A H^B}^{A*} = PAT_{H^A H^B}^{B*} = 1$ (Case 2).

The profits obtained by carriers A and B equal:

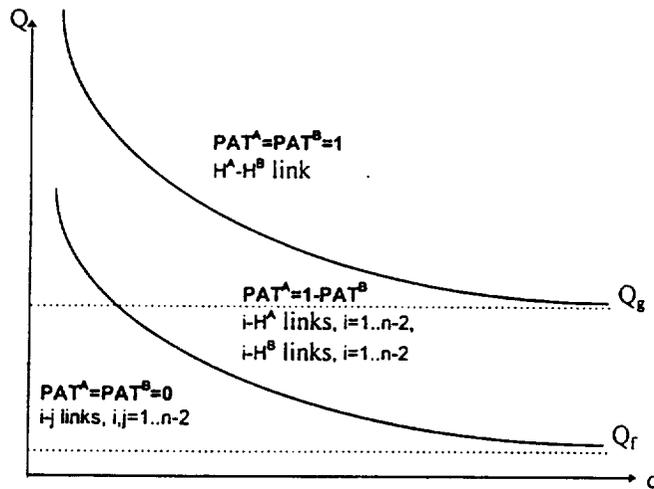
$$\pi^A = -2 \left\{ \begin{aligned} & \frac{1}{2} \sum_{i=1}^{n-2} \sum_{j=1}^{n-2} \frac{Q_{ij} d_{ij}}{b} + \sum_{i=1}^{n-2} \left(\frac{Q_{iH^A} d_{iH^A}}{b} \exp[b(p_{iH^A}^{A*}(i) - p_{iH^A}^{B*}(i)) + c] + (\alpha + \beta d_{iH^A}) \right) \\ & + \sum_{i=1}^{n-2} \frac{Q_{iH^B} d_{iH^B}}{b} \exp[b(p_{iH^B}^{A*}(i) - p_{iH^B}^{B*}(i)) - c] + \left(\frac{Q_{H^A H^B} d_{H^A H^B}}{b} + (\alpha + \beta d_{H^A H^B}) \right) \end{aligned} \right\} \quad (11a)$$

and

$$\pi^B = -2 \left\{ \begin{aligned} & \frac{1}{2} \sum_{i=1}^{n-2} \sum_{j=1}^{n-2} \frac{Q_{ij} d_{ij}}{b} + \sum_{i=1}^{n-2} \left(\frac{Q_{iH^B} d_{iH^B}}{b} \exp[b(p_{iH^B}^{B*}(i) - p_{iH^B}^{A*}(i)) + c] + (\alpha + \beta d_{iH^B}) \right) \\ & + \sum_{i=1}^{n-2} \left(\frac{Q_{iH^A} d_{iH^A}}{b} \exp[b(p_{iH^A}^{B*}(i) - p_{iH^A}^{A*}(i)) - c] \right) + \left(\frac{Q_{H^A H^B} d_{H^A H^B}}{b} + (\alpha + \beta d_{H^A H^B}) \right) \end{aligned} \right\} \quad (11b)$$

The two carriers have hub-and-spoke networks at equilibrium when the conditions represented on figure 2 are met:

**Figure 2 : Conditions for general hubbing at equilibrium
(the carriers have distinct hub locations)**



The cities served with connecting flights only are low density markets; the longer the distance between them, the thinner their traffic levels. Conversely, the cities served with direct flights only should correspond to high density markets, the density being higher as O-D distance is low. As the flights between the hubs themselves are supposed direct, the hub airports should be such that they generate high level traffic, which is the case of the "natural" hubs in Europe that form the basis of the flag carriers.

Furthermore, to obtain generalized hubbing at equilibrium, there must also be some markets where the mixed situation prevails ($PAT^A=1-PAT^B$): this situation can be interpreted as an unstable equilibrium, i.e. the competitive situation where two rival carriers choose the hub-and-spoke patterns might correspond to an unstable equilibrium. This result (equilibrium in mixed strategies) is a consequence of the model's structure, where the competing carriers are supposed to *simultaneously* choose their network pattern. The mixed strategies can be seen as reflecting each firm's uncertainty about its rival's choice. Consequently, the hub-and-spoke pattern can also appear as one of the best equilibrium pattern of an air carrier when faced with uncertainty.

Finally a last result of the model should be noted: because of the existence of the (non-empty) intermediary zone (equilibrium in mixed strategies where $PAT^A = 1-PAT^B$), the carriers – that were supposed to be *symmetric* – choose *asymmetric* network pattern at equilibrium.

III. EMPIRICAL TEST OF THE MODEL

The empirical work is currently being carried out on American data. An updated and complete version of the paper will be provided when results are available.

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Frequency Equilibria and External Costs in
Duopoly Airline Markets

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1. Introduction¹

As a result of the strong growth of air transport over the past decades, the external costs of aviation have become an important concern in public policy. In order to analyze the problem of externalities and formulate policy responses, one needs to know how decisions made in airline markets affect other sectors of the economy. It can be argued that in many transport markets, frequency of service is one of the main factors determining the external cost total in a market. In airline markets, for example, the size of externalities as noise and the emission of pollutants depends largely on the number of landings and take-offs. On the other hand, frequency of service is also a measure of quality in transport and as such affects consumer welfare. In order to analyze these conflicting effects on welfare, this paper models frequency equilibria in duopoly air transport markets.

The problem of frequency and fare determination in (air) transport markets is not new, nor is the basic spatial model used in this paper. Relevant articles using such a model include Panzar (1979), Greenhut *et al.* (1991) and Evans (1987). These articles, however, model airlines as monoproducer firms: each airline offers one flight and airlines enter the market until profit for each departure is zero. Norman and Stranden (1994) have modified the spatial model to allow for multiple departures in symmetric oligopoly equilibria. This paper presents an extension of the latter paper by modeling airline competition as a two stage game in frequency and prices, while allowing for asymmetric equilibria: when airline costs differ or consumer preferences are biased, the equilibrium frequency and price choices are not likely to be symmetric. Furthermore, the time structure implied in a two stage process seems relevant too: while prices may vary daily in the airline industry, departure frequencies are much less flexible.

The model is essentially an application of spatial multiproduct oligopoly to a circular air transport market.² Relevant spatial or localized models of multiproduct competition in a circular market are Martinez-Giralt and Neven (1988) and Bensaid and de Palma (1994). These papers analyze the three decisions of product number, location on the circle and price with inelastic demand and conclude that in the duopoly case, price competition can prevent product proliferation, i.e.,

¹Financial support from the Netherlands' organization for Scientific Research is gratefully acknowledged.

²We use an air transport market here, but the model applies just as well to other transport markets.

firms sell one product only. An important simplification here is that we make the assumption of exogenous maximal product differentiation and exogenous maximal interlacing. In the context of transport markets, this means that the time distance between successive departures (the 'headway') is assumed constant and equals the total time span considered divided by the number of departures. Furthermore, a departure of airline A is, if possible, always followed in time by a departure of a competing airline B: clustering of departures operated by one airline in time is minimized. We thus effectively take away the product positioning decision and focus on the product number and price decision in order to increase tractability. This is not to say that the choice of headway or position is not interesting or relevant. However, abstracting from this problem reduces complexity and allows us to focus on our main question of interest, the determination of frequencies and prices.

In the following section, we specify the basic model structure and analyze spatial multiproduct configurations. Then we discuss properties of frequency and price equilibria for the cases of inelastic and elastic demand. In section 3 we illustrate the model with numerical results using an empirical simulation model for the Amsterdam - Maastricht market. The resulting equilibria are used to evaluate the welfare effects of airline deregulation for alternative types of post-entry competition. Using a simple specification of the external cost function, the costs of noise annoyance and emissions are included in the analysis.

2. A model of airline competition

2.1. Demand

We consider a simple market for air transport, in which carriers offer consumers flights from some airport Y to some destination Z. A (potential) traveler derives gross utility \bar{v} from taking this trip, and faces a price p . For simplicity, we assume linear schedule delay costs: a consumer suffers a utility loss of θx when the flight leaves at a time distance $x = |t_{dep} - t_{pref}|$ from his or her preferred departure time.³ When the gross valuation exceeds the sum of price and schedule delay

³We thus make the assumption that the utility loss caused by taking a flight at a time distance x *earlier* than the preferred departure time is equal to the utility loss caused by taking a flight at x *later* than the preferred departure time. The term 'schedule delay cost' is meant to capture both types of utility loss.

cost, the traveler buys a ticket.

Potential travelers are distributed uniformly with respect to desired departure time on a circular market of (time) length $L = 1$ and density D . The departure times of flights are also located on this circle: we consider the departure times of flights i and $i + 1$, t_i and t_{i+1} respectively, which are separated by a headway H . Potential passengers who are 'located' at some preferred departure time $x \in (0, H)$ face a time distance x with respect to the departure time t_i of flight i and a distance $(H - x)$ with respect to t_{i+1} . These potential passengers derive the following net utilities or consumer surplus from the two options:

$$\begin{aligned} v_i &= \bar{v} - p_i - \theta x \\ v_{i+1} &= \bar{v} - p_{i+1} - \theta(H - x) \end{aligned} \quad (2.1)$$

Clearly, a consumer will choose the flight belonging to the larger of the above expressions and buy a ticket if the net utility is positive. We can now derive the distance x_b between t_i and the boundary between the market areas of the two flights as that x for which $v_i = v_{i+1}$. This gives

$$x_{b+} = \frac{p_{i+1} - p_i + \theta H}{2\theta} \quad (2.2)$$

All potential passengers located between t_i and x_{b+} will take flight i , if they fly at all, and those located between x_{b+} and t_{i+1} will choose flight $i + 1$, again, if they fly at all.

When potential passengers can decide not to take the trip, i.e., when aggregate demand is elastic, total demand for flight i from potential passengers with preferred departure times later than t_i can be obtained by adding the number of passengers over all preferred departure times x between t_i and x_{b+} , giving

$$q_{i+} = D \int_0^{x_{b+}} s(p_i + \theta x) dx \quad (2.3)$$

where $s(p_i + \theta x)$ is the share of potential passengers that do decide to fly. In order to arrive at total demand for flight i , q_i , we have to include the demand from passengers with preferred departure times earlier than t_i , q_{i-} . The derivation of q_{i-} is similar to the one used for q_{i+} outlined above.⁴ Therefore, aggregate demand for flight i is

$$q_i(p_i, p_{i-1}, p_{i+1}, H) = D \int_{x_{b-}}^{x_{b+}} s(p_i + \theta x) \quad (2.4)$$

⁴In the same way, there exists a location x_{b-} which marks the boundary between the market

Clearly, the specification of this demand function is crucial for the results.

2.1.1. Configurations

We now consider the multiproduct equilibrium. There are three possibilities: departure i operated by an airline l may have either two, one or zero neighbouring departures offered by a competing airline l ; we refer to such departures as 'unfriendly neighbours', while we call two neighbouring flights operated by one and the same airline 'friendly neighbours'.

The expression for the market boundary x_b in the demand per flight function q depends on the configuration of the departures. With an interlaced configuration, for each departure i the price for both the earlier and the later departure ($i-1$ and $i+1$ respectively) are set non-cooperatively by a competing airline.⁵ A departure i with two unfriendly neighbours faces market boundaries

$$\begin{aligned} x_{b-} &= \frac{p_{i-1} - p_i + \theta H}{2\theta} \\ x_{b+} &= \frac{p_{i+1} - p_i + \theta H}{2\theta} \end{aligned} \quad (2.5)$$

from which demand for flight is derived using equation (2.4). We refer to this type of flight as completely competitive. In the case of a 'semi-competitive' flight i , i.e., a flight with only one unfriendly neighbour $i-1$ and one friendly neighbour $i+1$, the price of the latter always equals the price of flight i . Therefore, this type of demand is derived using the boundaries

$$\begin{aligned} x_{b-} &= \frac{p_{i-1} - p_i + \theta H}{2\theta} \\ x_{b+} &= \frac{p_i - p_i + \theta H}{2\theta} = \frac{H}{2} \end{aligned} \quad (2.6)$$

For the sake of completeness, we note that for a non-competitive flight (with no unfriendly neighbours), demand is derived from the market boundaries $x_{b-} =$ areas of flight i and an earlier flight $i-1$ at time t_{i-1} , with

$$x_{b-} = \frac{p_{i-1} - p_i + \theta H_-}{2\theta}$$

⁵Note that in case of a duopoly the price of both competing departures is the same. Furthermore, each airline sets one and the same price for all its tickets.

$x_{b+} = \frac{H}{2}$. We conclude that for any demand specification, completely competitive demand is more price sensitive than semi-competitive demand.

For the market as a whole, we can now distinguish between two extremes. In a monopoly market, all departures are offered by the same airline; on the other hand, there is the completely interlaced equilibrium, in which all flights have unfriendly neighbours. Of course, there are many possible configurations between these extremes. The range of configurations implies that with multiproduct competition, monopoly and oligopoly become relative rather than absolute concepts. We consider two configurations in figure 1.

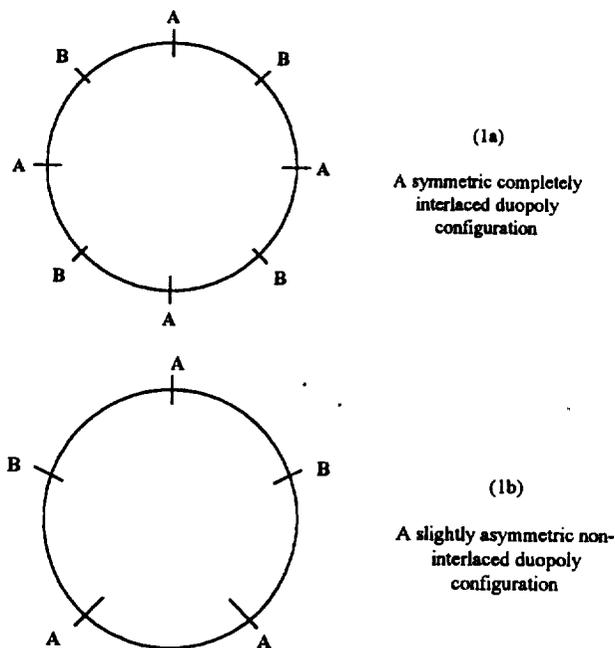


Figure 1: Multiproduct configurations

The first configuration in figure 1 is a completely interlaced duopoly. When a duopolist analyzes the effect of a small increase in departure frequency, he

necessarily considers a 'slightly asymmetric' configuration. As is illustrated in figure 1b, all non-symmetric duopoly configurations are non-interlaced.

2.2. Cost and profit

For each flight, costs consist of a (major) fixed part FC and a small marginal cost c per passenger.⁶ Revenue per departure is $p_i q_i$, so that profit for departure i is

$$\pi_i = (p_i - c)q_i - FC \quad (2.7)$$

When the total number of flights of a particular airline l is f_l , aggregate profits over all flights for this firm are given by

$$\Pi_l = \sum_{i=1}^{f_l} [(p_i - c)q_i - FC] \quad (2.8)$$

3. Market equilibria

The model analyzes frequency and price decisions as the outcome of a two-stage game in an airline duopoly. In the first stage, each airline chooses a frequency and in the second stage, each airline chooses a price given the first frequency choices. As usual in such a model, the solution is derived backwards by calculating the price solution first and using this solution in the calculation of the first stage frequency choice.

A stylized representation of the first stage frequency competition is given by the following pay-off matrix.

		airline 1	
		<i>low</i>	<i>high</i>
airline 2	<i>low</i>	(Π_{low}, Π_{low})	(Π_{high}, Π_{low})
	<i>high</i>	(Π_{low}, Π_{high})	(Π_{high}, Π_{high})

The symmetric cases on the diagonal are a dividing line. It has been outlined in the previous section that aggregate demand for airline 1 becomes less price elastic

⁶Fixed flight costs depend on aircraft capacity (type) k . Aircraft choice is mainly determined by the distance flown. Given the stage length of the city-pair market under consideration, k may be assumed constant.

when this airline has more flights than its competitor, i.e., when the configuration becomes non-interlaced. This is the case for the frequency pairs on the right hand side of the diagonal. For airline two, the same holds for the pairs on the left hand side of the diagonal.

The implication is that the form of the airlines' profit function changes at $f_1 = f_2$. The profit function of each airline therefore consists of two parts. Profits of airline 1 are

$$\Pi_1 = f_1 (p_1 - c) q_{cc} - f_1 FC \quad \text{if } f_1 < f_2 \quad (3.1)$$

$$\Pi_1 = (f_1 - f_2) (p_1 - c) q_{nc} + f_2 (p_1 - c) q_{cc} - f_1 FC \quad \text{if } f_1 \geq f_2 \quad (3.2)$$

The profit function of airline 2 has exactly the same form.⁷ Clearly, when the first line is relevant for one airline, the second is relevant for the other. Only when $f_1 = f_2$, the two parts of the profit function give the same value.

In order to derive results, we now turn to the specification of demand. We distinguish between inelastic and elastic aggregate demand in the following sections. In the next section, we assume that aggregate market demand is *inelastic*, e.g. as in Bensaïd and de Palma (1994). In other words, the reservation value \bar{v} is so high as to be never binding. In the case of elastic demand, some consumers buy a ticket and others decide not to fly.

3.1. Inelastic demand

In this case, all consumers fly and we thus have $s(p_i + \theta x) = 1$. Demand in (2.3) simplifies to

$$q_{i+} = D \int_0^{x_{b+}} 1 dx = Dx_{b+} \quad (3.3)$$

We now investigate the equilibrium frequency and price choices of the airlines and the resulting equilibrium configuration. In particular, we are interested in the question whether a symmetric and interlaced frequency choice emerges as an equilibrium.

3.1.1. Price equilibrium

As has been outlined in the previous section, the solution to the second stage price game depends on the configuration of departures: in a symmetric and thus inter-

⁷Note that the form of the profit function is dictated by the assumption of maximal interlacing.

laced configuration, pricing is competitive for all departures. In a non-symmetric duopoly configuration, at least two departures are friendly neighbours.

We consider the solutions for the price game, i.e., the simultaneous solution to the problem for each airline

$$\max_{p_l} \Pi_l(p_l, p_{-l}, f_l, f_{-l}) \quad l = 1, 2 \quad (3.4)$$

Like the profit function, the profit maximizing price consists of two parts:

$$\left. \begin{aligned} p_1^* &= c + \frac{(2f_1+f_2)\theta}{3f_2(f_1+f_2)} \\ p_2^* &= c + \frac{(f_1+2f_2)\theta}{3f_2(f_1+f_2)} \end{aligned} \right\} f_1 \geq f_2 \quad (3.5)$$

We define $d \equiv f_1 - f_2 \geq 0$ and write the difference between the profit maximizing prices as

$$p_1^* - p_2^* = \frac{(f_1 - f_2)\theta}{3f_2(f_1 + f_2)} = \frac{d\theta}{3f_2(f_1 + f_2)}$$

Clearly, in the symmetric departure solution, the ticket fares are equal. We note that with $f_1 \geq f_2$, the profit maximizing price of airline 2 p_2^* decreases in f_2 . p_1^* , however, increases in f_1 . The latter is quite intuitive, because the 'monopolisation' of the market by firm 1 increases in f_1 (for $f_1 \geq f_2$). With these price solutions in terms of frequency choices, we now turn to the frequency choice game.

3.1.2. Frequency equilibrium

The price solutions found in the previous section are now used to derive the frequency equilibrium. We consider the profit functions of both airlines given the second stage price solutions for $f_1 \geq f_2$.

$$\Pi_1 = f_2 D \frac{(2f_1 + f_2)\theta}{3f_2(f_1 + f_2)} \left(\frac{-d}{3f_2(f_1 + f_2)} + \frac{1+d}{f_1 + f_2} \right) - f_1 FC \quad (3.6)$$

$$\Pi_2 = f_2 \frac{D}{f_1 + f_2} \left(\frac{d}{3f_2} + \frac{(f_1 + 2f_2)\theta}{3f_2(f_1 + f_2)} \right) - f_2 FC \quad (3.7)$$

The profit function of airline 2 strictly decreases in its own flight frequency. Furthermore, both profit functions strictly increase in the frequency difference d . Therefore, we may already conclude that $f_1 = f_2$, a symmetric interlaced configuration, is not a likely equilibrium. The equilibrium frequency difference clearly

depends on the fixed costs per flight FC . If these would be zero, an equilibrium with a maximal frequency difference would prevail. For firm 2, the equilibrium choice is a 'minimal' frequency. For each value of f_1 (with $f_1 \geq f_2$), the best response of airline 2 is to minimize frequency. We refer to this minimum frequency, say 1 flight, as f_{\min} .⁸

Airline 1 chooses the profit maximizing frequency given the minimum frequency chosen by airline 2. The equilibrium frequency for airline 1 f^* is found by solving

$$\frac{2D(2f^* + f_{\min})\theta}{9(f^* + f_{\min})^3} = FC \quad (3.8)$$

The left hand side of the above expression decreases in f . If we let \overline{FC} be the value of FC for which $f^* = f_{\min}$ is the solution to (3.8), we may conclude the following.

Proposition 3.1. *The two-stage game of frequency and price choice with inelastic demand, exogenous interlacing and maximal product differentiation does not have a symmetric equilibrium for $FC < \overline{FC}$. For $FC \geq \overline{FC}$, there is a symmetric equilibrium with $f_1^* = f_2^* = f_{\min}$. For $FC < \overline{FC}$, the two asymmetric equilibria are (f^*, f_{\min}) and (f_{\min}, f^*) where f^* is the solution to (3.8).*

The proposition states the maximal frequency difference result: only for relatively high fixed costs ($FC \geq \overline{FC}$) a symmetric equilibrium is possible. With two identical firms, the equilibrium is not unique: both (f^*, f_{\min}) and (f_{\min}, f^*) are equilibria.

The equilibrium pay-offs differ between the two firms: the high frequency airline, say airline 1, earns a higher profit than the low frequency airline 2. In a symmetric equilibrium both airlines earn the same profit. However, for $FC < \overline{FC}$, an increase in the frequency of airline 1 raises its own profit, while it lowers the profit of airline 2. The pay-off structure of the frequency choice game is therefore a variation on a classic example in game theory named 'Battle of the Sexes' or 'Bach or Stravinsky' (Osborne and Rubinstein, 1994) in a gender neutral version. In this case, however, the positive pay-offs are not on the diagonal: referring to the matrix in figure 1, each airline wants to choose 'low' when the competitor

⁸If the airline further decreases frequency, it ceases to operate in the market.

chooses 'high' and vice versa, but both would rather have the high frequency.⁹ Just as in BoS there are two pure strategy equilibria, each with an asymmetric pay-off.

Finally, we note the similarity between the result of (maximal) differentiation in the number of products derived here and results in two-stage models of (monoproduct) differentiation. First of all, using quadratic transport costs in the model of two-stage duopoly competition in location and price, d'Aspremont et al. (1979) show that in the unique equilibrium, product (location) differentiation is maximal. Firms move away from each other's location in order to soften price competition. Note that the choice of location does not involve costs for the firm. In a model of vertical product differentiation or quality choice, Shaked and Sutton (1982) derive a maximal differentiation result too (despite the fact that quality is costless to produce); this equilibrium is, however, not unique when firms are identical. The latter two models have in common that the (maximal) differentiation result is driven by the price competition in the second stage.

In the present model, maximal differentiation in the number of products does not occur, except when fixed costs per product are zero. As we are dealing with frequency choice as the number of products, this assumption is not realistic. However, the result of differentiation causing an asymmetric frequency equilibrium remains.

3.2. Elastic demand

We now turn to the elastic demand model, where not all potential passengers necessarily buy a ticket and investigate how the equilibrium derived above is affected. A problem is that, even using simple specifications of elastic demand, equilibria in the above model become analytically untractable. Therefore, we have to confine ourselves to pointing out some properties of the elastic demand model and then illustrate the results with numerical solutions.

One of the important properties of the inelastic model is the strictly negative frequency derivative for the second airline. The elastic demand model, however, does not have this property. While we cannot present the reaction functions analytically, we derive an expression for the derivative of the profit function of

⁹In the BoS game, two people want to go to a concert together, but have different tastes. Their main concern, however, is to go out together. In our case, the pay-offs have shifted. The game is now 'Bach and Stravinsky' and describes the case where two people with identical musical taste want to avoid seeing each other at a concert.

the 'low frequency' airline with respect to frequency. The question is then whether the first order condition for profit maximization with respect to frequency may hold at all for the second or 'low frequency' airline.

We consider the profit function of the 'low frequency' airline. For this airline the profit function is now

$$\Pi_i = f_i ((p^* - c) q(p^*, f_i + f_{-i}) - FC) \quad (3.9)$$

The first order condition for the airline is then

$$\begin{aligned} \frac{\partial \Pi_i}{\partial f_i} &= ((p^* - c) q(\cdot) - FC) + f_i \left(\frac{\partial p^*}{\partial f_i} \left(q + (p^* - c) \frac{\partial q}{\partial p} \right) + (p^* - c) \frac{\partial q}{\partial f} \right) \\ &= (p^* - c) \left(q(p^*, f_i + f_{-i}) + f_i \frac{\partial q}{\partial f} \right) - FC = 0 \end{aligned} \quad (3.10)$$

The latter simplification follows from the envelope theorem: the effect of a frequency change on the equilibrium price cancels because the bracketed term that follows it is evaluated at the profit maximizing price p^* and therefore equal to zero. Thus, the sign of the profit derivative for the 'low frequency' airline is no longer strictly negative, but depends on the value of FC and on the sign of the second term in brackets in (3.10). The latter is strictly positive for particular demand structures, e.g. linear demand (see the appendix for details). Therefore, the result of maximal differentiation of the frequency choice no longer holds with elastic demand while the first order condition for profit maximization for the second airline may be satisfied in a symmetric equilibrium.

Proposition 3.2. *In the two-stage game of frequency and price choice with elastic demand, exogenous interlacing and maximal product differentiation, the 'low frequency' airline's first order condition for profit maximization with respect to frequency choice is no longer strictly negative and can be satisfied in a symmetric equilibrium. Therefore, a symmetric equilibrium may exist depending on the demand structure and the values of the demand and cost parameters.*

Obviously, the profit derivative in (3.10) decreases in the fixed flight cost FC . Furthermore, it can be shown that the product of the two terms in brackets and thus the profit derivative (3.10) increases in the schedule inconvenience cost θ . In other words, the marginal profitability of each flight increases, so that the equilibrium frequency increases in θ . The intuition is that for high θ , the relative importance of price in the utility function is small and thus price elasticity of demand is relatively low.

4. A simulation model

We illustrate the above results by presenting some simulation results, using a linear demand model. This demand model is based on Greenhut et al. (1987) and has the general form

$$q = 2Dx \left(\alpha - p - \frac{\theta x}{2} \right) \quad (4.1)$$

where α is a demand parameter. The frequency equilibria are derived by calculating first the best price responses of the duopolists in the second stage of the game for each set of frequency choices. Then we calculated the best frequency responses in the first stage of the game to obtain the Nash equilibrium while paying special attention to the role of the schedule inconvenience cost θ .

The values of the model parameters have been found by calibrating the model using actual data for the Amsterdam - Maastricht market. The calibrating procedure is similar to the one used by Norman and Strandenes (1994). At present, the Amsterdam - Maastricht route is a KLM monopoly. Therefore, observations for price, quantity and frequency for the years 1996 / 1997 have been substituted in the first order conditions for profit maximization with respect to price and frequency for a monopolist. Using these two conditions and the demand function, we were able to solve for the unknown parameters, viz., the intercept α , the schedule inconvenience cost (or 'shadow wage') θ and the density D .

Before proceeding to the results, we should say that the calibration procedure used here is rather crude so that the parameters obtained represent an order of magnitude. First of all, we constructed a price for a one-way ticket of Hfl 206,- as a weighted average of a number of full fare classes. We obtained the average number of passengers of 20 per flight from the CBS statistics, at a frequency of 5 flights on a typical day. We did not dispose of actual cost data. Therefore, we imposed an arbitrary marginal passenger cost of Hfl 25,- and a fixed flight cost of Hfl 2000,-.¹⁰

The elasticities of demand *per flight* with respect to price and frequency for the monopoly situation are respectively $\varepsilon_{q,p} = -1.14$ and $\varepsilon_{q,f} = -0.45$.¹¹ Using

¹⁰This fixed flight cost implies an approximate cost of 15 dollar cent per ASM. This cost figure is more than twice as high as the figure for US airlines using a B737-100 on average stage lengths of around 500 miles. The cost difference may be justified because of the much smaller stage length of 132 miles and the smaller aircraft, viz., the BA 146 (64 seats).

¹¹The elasticity of demand over all departures w.r.t. frequency is positive, 0.55, in the

these figures for the monopoly situation, we solve for the demand parameters. An overview of the parameters used in the base simulation is given in the table below.

Table 1:
simulation coefficients

calibrated parameters	
α	487.42
θ	83.33
D	0.023
exogenous parameters	
c	25
FC	2000

4.1. Simulation results

4.1.1. Identical airlines

Using these parameters in the two stage frequency price model, we have simulated airline duopoly competition between two identical airlines. The frequency equilibrium of this base case is symmetric. In equilibrium, both airlines operate 3 flights each at a ticket fare of Hfl 182,- .

as indicated above, both the equilibrium total number of flights and the equilibrium price increase in the schedule inconvenience cost. When θ increases, the relative price elasticity decreases and therefore the oligopolists are able to charge a higher price (for each frequency choice). This implies an increase in the profitability of the marginal flight, and thus to higher equilibrium frequencies. The latter also holds for decreases in the fixed flight cost FC .

However, changes in the parameters θ and FC may have an effect on the symmetry of equilibrium too. As explained in the previous sections, an important feature of the model is that it allows for asymmetric frequency choices. Asymmetry may occur for various reasons: with identical airlines, asymmetric configurations may occur due to the depressing effect of extra departures on the equilibrium price. It may be more profitable for an airline to choose a smaller frequency than the competitor; this confers monopoly power to the competitor which raises the

monopoly regime.

equilibrium prices of both firms.¹² We therefore conclude that both an increase in the schedule inconvenience cost θ and a decrease in the fixed flight cost FC have two distinct effects. On the one hand, both parameter changes increase the profitability of the marginal flight. At the same time, however, higher frequency choices have a depressing effect on prices. Therefore, the equilibrium frequency choice may be become asymmetric.

4.1.2. Non-identical airlines

When airlines are not identical, this in itself may result in asymmetry of the frequency equilibrium. Such asymmetry of airlines may be due to differing cost structures or consumers preferences for a particular airline (e.g. because of frequent flyer programmes). We illustrate both cases. Firstly, we present the case where airline 2 has fixed flight costs of Hfl 1000 in stead of Hfl 2000. Clearly, at all symmetric frequency choices the marginal profitability of a frequency increase will be higher for the second airline. Therefore, the frequency equilibrium will become asymmetric for two reasons: the low cost airline will increase its frequency because it has lower costs, which depresses prices. In order to temper price competition, the high cost airline decreases departure frequency.

Secondly, we analyze the case where all consumers have a preference for one of the two airlines. This preference is reflected in the utility function by a parameter b which is added to gross utility. We therefore have as the utility derived from flying with the preferred airline

$$v_{pref} = (\bar{v} + b) - p_{pref} - \theta x$$

in stead of the original utility function. In the simulation we have taken airline 1 as the preferred airline and use $b = 60$. Again, the frequency equilibrium is asymmetric because of both consumer preferences and the second stage price competition. The simulation results for the base case (identical airlines) and the two asymmetric cases are summarized in table 2 below. As a fourth case, the combined effect of cost difference and consumer preferences is presented.

¹²In the previous simulation, at a fixed flight cost of $FC = 1500$, the equilibrium is asymmetric. Equilibrium frequency and price choices are (4,3) and (186,177) respectively. If the 'low frequency' airline would raise its frequency, the resulting symmetric profit maximizing price choices would be so much lower (169,169) that a symmetric configuration is not an equilibrium.

Table 2: Simulation results

	airline 1	airline 2
Case 1: identical airlines		
frequency	3	3
price	182	182
Case 2: $FC_1 = 2000, FC_2 = 1000$		
frequency	2	7
price	171	207
Case 3: $b_1 = 60, b_2 = 0$		
frequency	4	2
price	199	177
Case 4: 1 and 2 combined		
frequency	3	6
price	177	184

4.2. Welfare effects of airline deregulation

The above results can be applied in order to analyze the welfare effects of airline deregulation in the case of the Amsterdam - Maastricht market. The welfare analysis clearly involves a number of assumptions. We assume here that with free market access, entry costs are such that one airline enters the market so that the KLM monopoly turns into a duopoly. We use the above cases of identical and non-identical competitors, and calculate the resulting welfare effects in terms of consumer surplus, profits and external costs.

In order to include the external costs of aviation in the welfare analysis, we make use of a simple external cost function: we take into account only the costs of emissions. As the measurement of social cost and the valuation of environmental goods fall outside the scope of this paper, we rely on the results Perl et al. (1996). Emission costs are calculated as

$$E = F(t \cdot v) \quad (4.2)$$

where F is the total flight frequency (number of landings and take-offs or LTO), t is the emission index (kilogram emitted per LTO) and v the value loss per unit of a particular emission type. Parameter values can be found in the appendix.

In the calculation of welfare effects we use the cases as presented in table 2, while referring to airline 1 as the incumbent and airline 2 as the entrant. The welfare results are presented in table 3.

The results show that welfare changes from deregulation depend critically on the type of entry and the resulting frequency equilibrium. As we have seen above, price competition is affected in two ways by frequency choice. First, the more symmetric the frequency equilibrium, the more intense the price competition; secondly, the higher total frequency, the more intense the price competition which depresses prices and increases consumer benefits. On the other hand, higher frequencies also lower schedule inconvenience (time) costs, which improves consumer welfare too. The four simulation cases illustrate the above mechanisms for different competitive contexts, all of which show a substantial improvement in the sum of consumer surplus and profits.

We briefly note a few interesting features. Comparing cases 1 and 2, we see an almost identical consumer surplus (change) for two very different equilibria. The high total frequency depresses price and lowers time costs, but this effect is countered by the 'monopoly power' of the low cost - high frequency entrant. These effects are at work in case 4 too, but here the effect of consumer preference (loyalty) with respect to the incumbent makes the equilibrium more symmetric. This results in higher consumer benefits than in case 2. In case 3 total frequency is lower because there is no low-cost entry, while the equilibrium is asymmetric: therefore, the increase in consumer welfare after entry is less than in the other cases. The difference between the cases with and without low-cost entry shows up clearly in the industry profit changes. With the large cost difference assumed here, industry profit after deregulation improves because the low-cost carrier captures a large market share.¹³ This effect makes the welfare changes even more pronounced.

Finally, the market outcomes allow us to calculate external costs as a function of departure frequency. Using the above simple specification of the external cost function, we are able to include emission costs in the welfare analysis. We note that this analysis only takes into account the emission part of the external cost total, while the parameters of the external cost function require further research. Also, capacity constraints and aircraft choice may be included in the analysis. In the present simulations, capacity constraints were not binding; however, in cases where capacity constraints are binding, (e.g. in Norman and Strandenes, 1994), the choice of aircraft type becomes relevant, which will clearly have an impact on the external cost parameters.

¹³Note, however, that the incumbent incurs profit losses in all cases.

Table 3: Welfare effects of deregulation

	Case 1	Case 2	Case 3	Case 4
Total number of departures	6	9	6	9
incumbent	3	2	4	3
entrant	3	7	2	6
Price (% change)				
incumbent	-11.8	-17.1	-3.3	-14.4
entrant	-11.8	0.2	-13.3	-10.7
Passengers (% change)	22.7	29.1	16.2	36.7
Consumer surplus (% change)	24.9	25.0	21.5	37.6
Profits (% of monopoly profit)				
incumbent	44.6	15.2	68.3	32.9
entrant	44.6	122.2	22.9	81.8
Aggregate profit (% change)	-10.8	37.4	-8.7	14.7
Profit + CS (% change)	17.1	34.9	14.2	43.5
Emission Costs (% of welfare sum)	0.07	0.09	0.07	0.08

5. Conclusion

The model developed in this article is an extension of the model in Norman and Stranden (1994). A first modification is that we model competition in frequency and prices as a two stage game: in the first stage, airlines choose frequencies, in the second stage they choose prices. As such, the model is similar to models of multiproduct oligopoly. A second modification is that we allow for asymmetric, non-interlaced frequency equilibria. The latter allows us to analyze competition between non-identical airlines.

The two-stage setup of the model allows airlines to choose frequency equilibria such that price competition is avoided. This feature is most pronounced in the case of inelastic demand, for which we have derived a maximal differentiation result. The latter result does not hold in the case of elastic (linear) demand. However, in the elastic demand case asymmetric equilibria do frequently occur. When competing airlines are not identical, asymmetric equilibria are particularly relevant.

The model allows us to analyze the welfare effects of airline deregulation for various types of post-deregulation entry, in terms of consumer surplus, profits and external costs. The size and distribution of the welfare effects prove to depend on the type of entry. Low cost entry results in the highest welfare gains, both as

a result of price decreases and of frequency increases. The latter, however, give rise to higher external costs. Therefore, the specification of technical and value parameters in the external cost function is an important extension of the paper in order to arrive at a complete welfare analysis of airline deregulation.

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A. Appendix

A.1. Sign of the profit-derivative of the low frequency airline in symmetric equilibrium

We consider the profit derivative of the 'low frequency' airline as given in (3.10). Given that price is above marginal cost in all equilibria (in other words, that airline profits are not negative), we have to show that the second term in brackets is positive, i.e.

$$q(p^*, f_i + f_{-i}) + f_i \frac{\partial q}{\partial f} > 0 \quad (\text{A.1})$$

We show this for the linear demand function which can be written as (see e.g. Greenhut et al., 1987)

$$q = \frac{DL}{2F} \left(\alpha - p^* - \frac{\theta L}{8F} \right) \quad (\text{A.2})$$

where α is a demand parameter. Note that both airlines have the same number of flights, i.e. $f = \frac{1}{2}F$, in a symmetric equilibrium. Therefore, we have

$$\frac{\partial q}{\partial f} = \frac{DL}{2F^2} \left(\frac{\theta L}{4F} - (\alpha - p^*) \right) \quad (\text{A.3})$$

Substituting (A.2) and (A.3) in (A.1), we find that in symmetric equilibrium

$$q(p^*, f_i + f_{-i}) + f_i \frac{\partial q}{\partial f} = \frac{6D}{F} (\alpha - p^*) > 0 \quad (\text{A.4})$$

The latter holds because α is the demand intercept or the maximum price consumers are willing to pay. Therefore, the term in brackets on the RHS of the equality sign is positive and we may conclude that the profit-derivative is not strictly negative; rather, it's sign depends on the value of the fixed flight cost FC .

A.2. Emission costs

In the calculations, the following parameter values have been used.

- Emission index t (kilogrammes per LTO):
 - NO_x : 4.85
 - HC : 1.52
 - SO_2 : 0.32
 - CO : 12.03
 - CO_2 : 1855.08
- Value estimates v are the "Urban/potential" values reported in Perl et al. (1996).



**THE USE OF MARKET POWER IN INTERNATIONAL
AVIATION AND TOURISM**

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**THE USE OF MARKET POWER IN INTERNATIONAL AVIATION
AND TOURISM**

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Abstract

In order to make international trips, visitors must use some form of transport, such as aviation. Countries possess a degree of market power over tourism within their borders, and they often seek to use this. This market power also transfers over to aviation; they control air routes jointly with their trading partners, and they often restrict supply, sometimes with the intention of generating profits. However, they must share traffic and profits with their partners. Governments also levy taxes on tourism, but these affect domestic tourists and residents. A model is developed which combines all these features. It is possible to use it to characterise the best possible combination of aviation and tourism policies from the perspective of an individual country. A country typically does not have full control over aviation policies, and this can be allowed for. What is desirable from the perspective of an individual country is not desirable from a world perspective. In tourism, and to a lesser extent, countries are able to levy optimum tariffs, which benefit themselves but lessen overall world welfare. There is evidence that countries are becoming more aware of their market power; as international aviation becomes increasingly liberalised, countries are imposing more taxes on tourism.

1. Introduction

In recent years countries have been explicitly recognising that they possess market power in international aviation to their borders. They share this power with other countries on the routes they control. Granted this, they have been questioning what policies are best from their own viewpoint. Even countries predisposed to take a liberal view are noting that their airlines may be profiting from regulation on some routes, and that it may be travellers from other countries who are paying the higher prices which enable these profits. In effect they may be able to levy an optimum tariff on aviation, though their ability to do so depends on their partner's policies. While individual countries may gain from imposing restrictive policies, from a world perspective, a liberal environment would be more efficient. Part of the unwillingness of some countries to liberalise may be explained by this; it may not be simply a matter of them being protectionist towards their airlines.

International aviation is linked to international tourism; they are close complements. If there are no distortions at the tourism level, it will be sufficient to examine international aviation on its own. This is unlikely to be the case, since even if tourism is not specifically taxed, the goods and services purchased by tourists will normally be subject to general taxation, such as VAT, which creates a divergence between what tourists pay and the cost of provision. Further, tourism is often seen by countries as a generator of positive or negative externalities. Tourism is sometimes taxed for revenue raising reasons. Taxes such as accommodation taxes are intended to be passed on to the tourist, who is often from another country. If this is so, it is necessary to consider international aviation policy together with tourism policy: they cannot be analysed in isolation from one another.

From a worldwide efficiency perspective, tourism taxes pose even more difficulties than aviation regulation. It is easier for countries to increase this taxation, as the taxes are spread over tourists from across a range of countries, and no one country is likely to find it in its interest to retaliate to a country's tourism taxes. The countries whose nationals pay the tax have less countervailing power than they do in aviation. Tourism taxes are a trade distortion which will be very difficult to negotiate away, since it is in some countries' individual interest to levy them. Indeed, as countries are under more pressure to liberalise their international aviation, they may be relying more heavily on taxation of tourism instead. Trade liberalisation at the airline level has been very difficult to accomplish; liberalisation at the tourism level may be even more difficult.

For many countries, such as Australia, most tourists come by air. Thus, policies which affect costs and prices of international aviation affect the gains from tourism. This link is perceived, though not often examined. (For some discussion, see Findlay and Forsyth, 1988, and some recognition, Productivity Commission, 1998). Thus tourism interests always support low air fares, and airlines claim they are creating externalities by bringing tourists; there is little guidance as to where the best mix of policies might lie. The question of how the benefits from tourism and international aviation can be maximised is considered in this paper.

The Policy Environment

A government which seeks to maximise the benefits from aviation and tourism for its own citizens must operate in an environment which constrains it. It can raise prices for tourism services, but residents touring at home will be affected as well as foreigners. It is often difficult to discriminate between them. Residents also make international trips - it can be difficult to distinguish between residents and foreigners on international aviation (though ways exist and are used). When tourists come to a country, they create externalities, positive and negative. These could be significant, yet difficult to correct for. On international routes, traffic and profits are normally shared by airlines of different countries. A route is jointly regulated by governments at either end, and no one government can obtain its preferred form and level of regulation. Subject to their partner's preferences, governments do have some freedom to choose international aviation policies.

It should be apparent from the list of factors above that there are no simple policy prescriptions for tourism and aviation from an individual country's perspective. The best set of policies depends on the balance of forces that applies in a particular case. The ways these interact can best be shown by setting out a formal model, and this is done in this paper. The purposes are to characterise the key relationships, and thereby elucidate the policy choices available to a government. No empirical data are examined - this can be readily done, as the model is quite adaptable to empirical application. The paper thus cannot come to firm policy conclusions, though some suggestions are made.

In section 2, the model is outlined, and in section 3 it is analysed. Several different variants of the model (e.g. corresponding to different constraints on the home government) are considered. The model supposes a simple market structure for international air routes - this is subjected to scrutiny in section 4. It is recognised that any country must operate within the bounds set by the policies of others - the consequences of this are considered in section 5. In section 6, the application to Australia is discussed, and in section 7, some problems posed for efficiency at the worldwide level are considered.

2. A Model of Tourism and International Aviation

The key aspect of this model is that tourism and international aviation are jointly consumed services. Tourists come to a country by using international aviation services. It is taken that there are no alternatives - this is effectively true of countries such as Australia, New Zealand and Japan. It is less true of the U.K. and not true at all of many European nations. It would be possible to generalise the model to allow for non-aviation means of transport, but this is not allowed for here. It is also assumed that the services are consumed in fixed proportions. Again this need not be the case - international visits can be of varying durations, and it is likely that duration would depend partly on relative prices of the travel and tourism components. This could be allowed for at the cost of additional complexity.

Another key feature of the model is that both home and overseas tourists use tourist facilities in the home country, and home and overseas tourists use international aviation. Total tourism in the home country is given by h , the sum of domestic (d) and overseas (v)

tourists. Overseas visitors v are the sum of visitors from all other countries, $i = 1 \dots n$. (Consider the home country as country 0.) Thus:

$$h = d + \sum_{i=1}^n v_i \quad (2.1)$$

The total number of residents travelling overseas, a , is equal to the sum of those visiting other countries, $\sum_{i=1}^n a_i$. The number of persons travelling between 0 and i is given by m_i .

$$m_i = a_i + v_i \quad (2.2)$$

Tourism is assumed to include all travel, whether for business, leisure, or other purposes.

Tourism services in the home country are supplied at constant marginal cost, c_h . Aviation services between the home country and country i are supplied at constant marginal cost s_i . Finally, the price to residents who travel abroad of tourism services in country i is given by c_i . This may or may not equal marginal cost, but from the home country point of view, it is fixed.

The prices charged for home tourism and aviation services need not equal marginal costs. It is assumed that tourism services are "taxed" at a rate t_h , so that the price of tourism in the home country, p_h , is given by

$$p_h = c_h + t_h \quad (2.3)$$

Aviation services may be taxed, at a rate r_i , such that the price of a trip to/from i , P_i , is given by

$$p_i = s_i + r_i \quad (2.4)$$

The overall price of a trip, including the tourism component, for a resident visiting i , p_a^i is given by

$$p_a^i = c_i + s_i + r_i \quad (2.5)$$

and the overall price to a visitor from i , p_v^i , is given by:

$$p_v^i = c_n + t_n + s_i + r_i \quad (2.6)$$

These 'taxes' can be interpreted in several ways. Basically they represent divergences between prices and marginal social costs. In the case of tourism, it could be that a general tax is levied (e.g. a VAT) on services which tourists purchase. Specific tourism taxes, such as accommodation taxes, could be levied. Alternatively, it may be the case that there are externalities associated with tourism, and c_h represents the marginal social cost of tourism services and t_h is interpreted as a divergence between price and marginal social cost. It could be negative - tourism may create negative externalities. It could be that some of the resources used to provide tourism services are priced above or below their shadow prices - for example, if there is unemployment, the wages of labour may exceed its shadow price. Finally, there may be monopoly in parts of the tourism industry, and

prices may be above marginal cost. For most purposes, it does not matter which of these explanations of divergence of price from marginal cost is operative. However, in one case, it is necessary to be more explicit: this is the case of a shadow price of government revenue differing from its nominal value. In such a case, it matters whether the government gains can amount, t_h , through taxation, or whether individuals gain it, e.g. in the form of an externality.

With the 'tax' on aviation services, the same points can be made. However, the interpretation is most likely to be in terms of firms setting prices above marginal costs. Direct taxation of international aviation is not likely to be significant. Governments, however, regulate aviation, and this regulation helps determine prices. For example, capacity may be restricted, and airlines may raise prices. Sometimes governments own the airlines serving international routes, and profits accrue to them. Again, if special attention is to be given to the shadow price of government revenue, the model needs to be adjusted to make this explicit.

Few countries have airlines which possess a monopoly of traffic on the international routes. In some cases, countries at either end of a route, and perhaps others as well, can compete for traffic. More common is the situation of where countries allocate a share of traffic between each other. Either this takes place explicitly in bilateral air services agreements, or implicitly (if a country's share becomes too small, things are changed to increase it). In this model, it is assumed that the home country has a share of traffic to country i of θ^i . Thus, the profits on route i gained by the home country would be

$$\theta^i r^i m^i = \theta^i r^i \cdot (a^i + v^i). \quad (2.7)$$

In practice, pooling agreements often exist between airlines, and profits are not proportional to traffic. The payoff to greater detail here is unlikely to be worth the cost.

Residents have a utility function such as

$$u = u(a, a_1, a_2, a_3 \dots a_n, x) \quad (2.8)$$

where x refers to all other goods. They maximise utility subject to

$$p_h z + p_x x + \sum_{i=1}^n p a^i \cdot a^i = y \quad (2.9)$$

where y is home income. This gives rise to demand functions

$$h = h(p_h, p_x, p^1, p^2, \dots, p^a, \dots, p^n, y) \quad (2.10)$$

$$a_i = a_i(p_h, p_x, p^1, p^2, \dots, p^i, \dots, p^a, \dots, p^n, y). \quad (2.11)$$

The demand for tourism to the home country from country i is given by:

$$V_i = v_i(p^1, \dots, p^i, \dots, p^n, y^i) \quad (2.12)$$

These functions are deliberately written with scope for considerable substitution. Thus (10) allows for the (likely) effect that changes in home tourism prices will affect demand

for overseas tourism. Destinations can be substitutes for one another; this possibility is discussed in Section 3.

In this model, the government of the home country can be taken as maximising benefits for its residents. It values consumers surplus of residents, and producers surplus from production, along with net tax revenues. It does not value the consumers surplus of foreign visitors - it only values profits and taxes generated by their spending. It cannot price discriminate between the two, however. Problems similar to this one have been analysed by Peston, Katz and Gravelle (1976) and Auquier and Caves (1979). The problem of making the most from foreign tourism has been considered by Tisdell (1984).

3. The Working of the Model

The home country can be taken to be maximising an expression of the form of (3.1).

$$\begin{aligned}
 W = & B(d(p_h, p_a, p_x), \dots, a^i(p_h, p_a, p_x), \dots, \\
 & a^n(p_h, p_a, p_x), X(p_h, p_a, p_x) - d()c_h - \sum_i a^i()p_a^i - p_x x \\
 & + (p_x - c_x)x + \sum_i v^i(p_h, p_v)t_n + \sum_i \theta_{r_i}(a^i(p_h, p_a) + v^i(p_h, p_v)) \quad (3.1)
 \end{aligned}$$

where p_a and p_v are vectors of trip costs to residents and foreign visitors, respectively, over the n destinations/origins. The country is assumed to be maximising the benefits to residents making home and overseas trips and consuming other goods, x , less the cost of home tourism and the cost of overseas tourism to residents and the cost to residents of other goods $p_x x$. To this is added the producers surplus or tax on sale of other goods, the surplus/tax from selling tourism services to foreign visitors, plus the country's share of airline profits. This is maximised subject to a resource constraint which allows for the fact that taxes on foreign tourists augment resources available.

The inclusion of 'other goods' in 3.1 is to highlight the possibility that there can be interactions between travel and other goods. They may be substitutes or complements. If these other goods are not priced at marginal cost, changes in travel prices can affect tax receipts from sale of the goods. To make the model less cumbersome, it will be assumed that these interactions are not important - either travel is not closely related to other goods, or prices approximate marginal cost and a more partial framework will be used. The term $B()$ will be taken to be a money metric indicator of consumer's benefits, dependent only on travel and tourism prices. The maximand can then be reduced to W^1 in 3.2.

$$\begin{aligned}
 W^1 = & B(d(p_h, p_a), a^1(p_h, p_a), \dots, a^i(p_h, p_a), \dots, a^n(p_h, p_a)) \\
 & - d()c_h - \sum_i a^i()p_a^i + \sum_i v^i(p_h, p_v)t_n \\
 & + \sum_i \theta_{r_i}(a^i(p_h, p_a) + v^i(p_h, p_v)) \quad (3.2)
 \end{aligned}$$

This is similar to a consumers surplus plus producers surplus maximand. The government chooses the tax/profit rates t_h and r^i so as to maximise 3.2. This results in first order conditions.

$$\begin{aligned} \frac{\partial v^i}{\partial a_h} &= \frac{\partial \pi}{\partial a_i} \frac{\partial a_i}{\partial p_h} + \sum_i \frac{\partial \pi}{\partial a^i} \frac{\partial a^i}{\partial p_h} - \frac{\partial c_h}{\partial p_h} - \sum_i \frac{\partial v^i}{\partial p_h} p^i \\ &+ \sum_i \frac{\partial v^i}{\partial p_h} t_h + \sum_i v^i (') \\ &+ \sum_i \theta r^i \left(\frac{\partial a^i}{\partial p_h} + \frac{\partial v^i}{\partial p_h} \right) = 0 \end{aligned} \quad (3.3a)$$

$$\begin{aligned} \frac{\partial v^i}{\partial r^i} &= \frac{\partial \pi}{\partial a^i} \frac{\partial a^i}{\partial p^i} + \sum_{j=1}^n \frac{\partial v^j}{\partial p^i} \frac{\partial \pi}{\partial a^j} - \sum_{j=1}^n \frac{\partial v^j}{\partial p^i} T^j - a^i (') - \frac{\partial c_h}{\partial p^i} \\ &+ \sum_{j=1}^n \frac{\partial v^j}{\partial p^i} t_p + \sum_{j=1}^n \theta r^j \left(\frac{\partial a^j}{\partial p^i} + \frac{\partial v^j}{\partial p^i} \right) + \theta_i (a^i (') + v^i (')) = 0 \end{aligned} \quad (3.3a)$$

It is assumed that the second order conditions for a maximum are satisfied - this is plausible. The terms $\frac{\partial \pi}{\partial a_h}$, $\frac{\partial a^i}{\partial p_h}$, $\frac{\partial v^i}{\partial p_h}$ can be replaced by $\frac{\partial \pi}{\partial a_h}$, $\frac{\partial a^i}{\partial a_h}$, $\frac{\partial v^i}{\partial a_h}$, respectively, and the terms $\frac{\partial v^i}{\partial p^i}$, $\frac{\partial v^j}{\partial p^i}$ and $\frac{\partial v^j}{\partial p^i}$ can be replaced by $\frac{\partial \pi}{\partial p^i}$, $\frac{\partial v^j}{\partial p^i}$ and $\frac{\partial v^j}{\partial p^i}$ can be replaced by $\frac{\partial \pi}{\partial p^i}$, $\frac{\partial v^j}{\partial p^i}$ and $\frac{\partial v^j}{\partial p^i}$, respectively.

The equation (3.3a) can be interpreted as balancing the changes in consumers surplus on overseas and domestic travel by residents plus tax/surplus on domestic tourism resulting from a rise in domestic tourism prices (1st four terms) with the change in tax/surplus on foreign tourism plus the change in the share of profits in aviation. The equations (3.3b) balance the consumers surplus changes with producers surplus changes brought about by a change in the profit margin/tax in aviation on route i , r^i . These terms are too general to provide much insight into the workings of the model. Simplification is called for, and it is probably best to start with the simplest model, and add additional complexities.

The Two Country Model

Suppose that there are only two countries, the home and foreign countries. Suppose also that, for residents, domestic and overseas travel are unrelated

$$\left(\frac{\partial \pi}{\partial a} = 0, \frac{\partial a_h}{\partial a_h} = 0 \right).$$

Suppose that consumers maximise such that $\frac{\partial \pi}{\partial a_i} = p_h$, $\frac{\partial \pi}{\partial a^i} = p_a$.

Foreign tourists are indifferent between a change in trip cost caused by a rise in tourism prices, p_h and an equal rise in air fares, i.e. $\frac{\partial v^i}{\partial a_h} = \frac{\partial v^i}{\partial a^i}$.

The first order conditions now reduce to

$$\begin{aligned} p_h \frac{\partial \pi}{\partial a_h} + c_h \frac{\partial \pi}{\partial a_h} + \frac{\partial v^i}{\partial p_h} t_h + v^i (') + \theta r^i \frac{\partial v^i}{\partial a_h} &= 0 \\ - a^i (') + \frac{\partial v^i}{\partial a^i} t_h + \left(\frac{\partial v^i}{\partial a^i} + \frac{\partial v^i}{\partial a^i} \right) + \theta (a^i (') + v^i (')) &= 0 \end{aligned} \quad (3.4)$$

To simplify matters further, suppose the country obtains all the profits from aviation ($\theta = 1$). On rearranging these conditions we get

$$\begin{aligned}\frac{\partial d}{\partial t_h} t_h &= - (r \frac{\partial v}{\partial t_h} + t_h \frac{\partial v}{\partial t_h} + v) \\ \frac{\partial r}{\partial a} r &= - (r \frac{\partial v}{\partial a} + t_h \frac{\partial v}{\partial a} + v)\end{aligned}\quad (3.5)$$

Given that $\frac{\partial v}{\partial a} = \frac{\partial v}{\partial p_a}$, it can be shown that

$$\frac{t_h}{p_a} (r/p_a)^{-1} = (\varepsilon_d / \varepsilon_a) (a/d) \quad (3.6)$$

where ε_a is the elasticity of demand for overseas trips by residents by ε_d is the elasticity of demand for home tourism by residents. Equation (3.6) states that the relative weights put on tourism and aviation taxes depends on the elasticities of demand for overseas and home trips by residents, and the levels of overseas and home tourism (foreign visitors do not affect the balance between these because they are equally affected by tourism or aviation taxes, and all taxes accrue to the home government). To determine how the taxes should be levied, it is a matter of balancing marginal distortions to home and overseas tourisms by residents.

Equations 3.5 can also be expressed in the form

$$\begin{aligned}\varepsilon_d d \frac{t_h}{p_a} &= - \varepsilon_v v \left(\frac{r+t_h}{p_a} \right) - v \\ \varepsilon_a a \frac{r}{p_a} &= \varepsilon_v v \left(\frac{r+t_h}{p_a} \right) - v\end{aligned}\quad (3.7)$$

where ε_v is the elasticity of demand for tourism by foreign residents. These equations indicate that the level of taxes depends on the elasticities of demand and the ratio of foreign to domestic tourism (the higher the foreign relates to domestic tourism, the higher the tax). These equations balance distortions to residents as against revenue from foreign tourists.

Few countries are able to appropriate all the surplus earned in aviation - normally they must share them with other countries. An alternative, extreme, assumption is that a country enjoys no surplus from aviation ($\theta = 0$). If this were so, the home country would seek as low an r as possible (to increase demand for tourism and take its profit on tourism). For a given r , it would balance the revenues for tourism with the distortionary costs to residents consuming local tourism services.

The most plausible case is where $0 < \theta < 1$. As θ varies, the balance between tourism and aviation taxes will alter. Normally, as θ falls (and the home country gains a reduced share of airline profits), the reliance on tourism taxes will increase. Let Z stand for $\frac{t_h}{p_a} (\frac{r}{p_a})^{-1}$. Then it can be shown that

$$\frac{\partial Z}{\partial \theta} = (v+a) \frac{p_a}{r} \frac{1}{\varepsilon_d} d + \frac{a}{d} \frac{\varepsilon_d}{\varepsilon_a} \quad (3.8)$$

The second term is normally positive, but probably much less than unity. The first term is negative, and $(r+a)/d$ could be less or greater than unity, $\frac{1}{\epsilon_a}$ about unity and negative and $\frac{r}{\theta}$ well above unity. Thus, $\frac{d}{\theta}$ is likely to be negative. As θ falls, it is possible that the optimal choice of r will become negative. Since the other country is enjoying most of the airline "profits", it could be in the home country's interest to have aviation subsidised, so that it can reap more through tourism taxes.

It is possible that one or other of the 'tax' rates will be set exogenously. For example, a country's aviation partner may insist on having a tax or profit rate on aviation of a certain level. If so, it can be shown that as r , the constrained aviation tax rate, falls, the tourism tax will normally rise to compensate it. The rise will be larger the greater is θ . This result may not hold when the possibility of home tourism prices affecting overseas travel by residents, and overseas trip prices affecting home tourism prices affecting overseas travel by residents, and overseas trip prices affecting home tourism, are allowed for. An alternative constraint may be where it is difficult for the government to alter the 'tax' on home tourism. It may be difficult to levy a tax on the many services which constitute 'tourism'. If so, the government can only work through aviation taxes or profits. Normally, the higher the price/marginal cost ratio in tourism, the lower the desired tax/profit rate in aviation.

The Three Country Model

Additional possibilities are opened up when it is supposed that the home country has links with two different overseas countries. To simplify matters, suppose that $\theta_1 = \theta_2 = 1$ - i.e. the home country gains all airline profits. After rearranging, the first order conditions can be written as

$$\begin{aligned} \frac{1}{p_h} d \epsilon_h &= \frac{r^1}{p_a^1} a^1 \epsilon_a^1 + \frac{r^2}{p_a^2} a^2 \epsilon_a^2 \\ \frac{r^1}{p_a^1} &= - \frac{1+r^1}{p^1} \frac{v^1 \epsilon_v^1}{a^1 \epsilon_a^1} - \frac{v^1}{a^1 \epsilon_a^1} \\ \frac{r^2}{p_a^2} &= - \frac{1+r^2}{p^2} \frac{v^2 \epsilon_v^2}{a^2 \epsilon_a^2} - \frac{v^2}{a^2 \epsilon_a^2} \end{aligned} \quad (3.9)$$

The first equation is the equivalent of (3.6), only this time the distortions in two international aviation markets are being considered. The second and third equations correspond to 3.7. there are two price/marginal cost ratios, corresponding to the two routes, to be determined. They depend on elasticities and shares of traffic. In general, one would not expect that the elasticities ϵ_a^1 and ϵ_a^2 or ϵ_v^1 and ϵ_v^2 would differ by much - estimates of elasticities for international aviation are not very reliable either. However, the ratio v/a , is the proportion of foreign to resident traffic on particular routes can vary widely. Thus, differential pricing on air routes is likely to be warranted not so much by elasticity differences (the standard price discrimination case), but rather by differences in traffic flow. Countries might well seek to have high prices and profits on routes for which they have a higher share of the profits, but a low share of the passengers.

Generalising the Model

The extension from 2 to n countries will not produce results which are qualitatively very different from those discussed. There can be quantitative differences, however, and these, in practical terms, can be important. Suppose that t_h and r^j have been set for a large number of countries, and that a particular route is being considered (perhaps it is to be opened up). The solution to the optimisation problem will involve new values for all r^i and for t_h . Unless the route is very large (and new routes are unlikely to be), changes will be small. Thus, for purposes of analysis, t_h can be taken as given. The rate of tourism tax/profit, t_h , will only be changed in a many country world when aviation policy towards all countries and tourism policy is being considered. For the new route, j , r^j is optimised with t_h taken as given - the profit/tax on substitute/complement routes, i , r^i , could well vary substantially when r^j is changed however.

Another aspect worth considering in practice are the demand interactions between different services. Domestic tourism prices affect overseas travel by residents, and overseas trip prices affect domestic tourism. This can have a considerable bearing on the actual relationship of tourism and aviation prices. It is probable that domestic tourism is much larger than overseas tourism, (i.e. $d > a$) and that the cross elasticity of overseas tourism with respect to domestic prices is quite high. If currently the price/marginal cost ratio in domestic tourism is high, and the aviation tax is low (or the home country's share is low), raising domestic tourism prices may be an ineffective way of gaining a greater profit from foreign tourists - it simply induces the locals to go overseas.

Another interaction which can prove important is that between traffic, or residents and foreign tourists, on international air routes. There are often several ways of travelling from country A to country B - directly, or via country C, country D and so on. Prices charged on indirect routes affect the prices that can be charged on direct routes. Thus, Sydney-Singapore (and then to London) is a substitute for Sydney-London. This means that for a particular route, the choice of price and profit/tax level can be tightly constrained by prices on other routes. Another consequence is that the indirect effects on other routes of a choice of price or profit/tax for a particular route can be large relative to the direct effects.

It is a straightforward matter to generalise this model to allow for the possibility that government revenue is valued at above its nominal value (because, to raise revenue, it is necessary to impose taxes) (see Findlay and Jones, 1982, and Browning, 1987). It would involve multiplying government revenue changes by the appropriate shadow price. To estimate the effects, it would be necessary to specify effectively what proportion of the difference between prices and marginal social costs of home tourism services was due to taxes/subsidies, and what due to profits and externalities. It would also be necessary to specify what proportion of the difference between prices and marginal costs in aviation accrue to the government in the form of taxes or shares of airline profits.

Allowance for this would not make the results very different qualitatively. It could affect the balance of policies, however, especially if the shadow price of government revenue were considerably higher than the nominal value. If, for example, the government's share of aviation profits were small in relation to its share of tourism profits, the balance of

taxes would shift towards tourism. Demand interaction, especially between domestic and overseas tourism for residents, would become more important.

Another possibility that can be allowed for is that the shadow price of foreign exchange differs from its market price. This difference is unlikely to be large for most developed countries, but it could be significant for many developing countries, and the foreign exchange aspects of tourism could be important for them. It would be necessary to identify the foreign exchange flows arising from the various expenditures - or domestic tourism, and residents' trips overseas - and the flows which arise at the airline level.

If the shadow price of foreign exchange were significantly higher than the market price, this could result in quantitatively different results. The country would have an incentive to shift the balance of taxation towards airlines and away from domestic tourism - in order to dissuade its residents from taking overseas trips and using up foreign exchange. It would also wish to lower the overall level of taxation of tourism and aviation. This would encourage more tourism by foreigners, which would have the advantage that it would generate more foreign exchange.

4. Airline Policy

In the preceding Sections, little has been said about the ownership and market structure of airlines - they are taken to provide services that tourists use, and the difference between their marginal costs and prices is assumed to be taxes. It is necessary to be more explicit about them, and investigate whether ownership or market structure may be a constraint on aviation policy.

The simplest case is one where there is a government owned airline, and capacity or fares are regulated. Given a level of costs, these determine the profits earned by the airline, all of which accrue to the government. It is equivalent to the government setting a tax on airline services. This situation used often be the case- governments often wholly owned airlines, and they regulate capacities or fares on routes. Overall, government airlines were not notably profitable, perhaps because they cross-subsidise loss making routes, from profitable routes. The airlines may not be profit maximising firms; if the government gave incentives for its firms to maximise profits, the result might be very similar to the case outlined in the model above. Regulation was often for protection rather than profit.

If the sole airline were privately owned, it might be more oriented towards profit (though it need not be, and as a regulated firm it may be required to offer unprofitable services). The main difference is that the profits would accrue to the owners, not the government. If all that matters is which country receives the profits, this case would equally well fit the model. A possible complication is that the value of revenue to the government may exceed its nominal value - if so, this would need to be allowed for in the model, and it would be necessary to specify who owns the airline.

The approach as characterised in the model in Sections 2 and 3, whereby the government levies a tax on international aviation services, was probably a reasonable approximation for many airline routes. However, it should not be taken too literally. Governments rarely actually impose significant taxes on international aviation services - it would be too difficult to do so with other countries' airlines operating them and other countries'

governments sharing the task of regulation. Sometimes minor taxes, such as airport or departure taxes are levied, but in the main, if a country wishes to levy a "tax" on international aviation, it does so through regulation which has the effect of raising prices and profits.

Competition for the Market

A system such as that outlined may have little in the way of incentives for efficient performance. These can be enhanced within the same framework of capacity or price controls by allowing competition for the market. A country would negotiate the rights to offer a certain amount of capacity to another, or operate worth at a specified fare. The government could then award the route to the airline which bid the most for it; this would provide an incentive for minimum cost production, and profits would go the government.

The successful bidder might be drawn from one of the country's airlines, public or private. If the government were minded to allow trade in airline services, airlines from any country might be permitted to bid, subject to this being acceptable to the other country on the route. If capacity, not price, is controlled, a minimum, not maximum, price will be set. It is possible that profit oriented airlines would set prices above the level that would ensure full use of the permissible capacity. This price would be above the level regarded by the government as optimal given the tourism implications. Apart from this, the main proposition will hold - it is possible for the country to secure minimum cost production, and maximisation of the rents from aviation, within the context of an aviation/tourism pricing policy. It is also possible for it to import airline services if it chooses.

Competition

If competition in the market is allowed, the government loses control over price. As the market becomes more competitive, airlines tend to set prices closer to marginal cost: prices may approximate marginal cost. If the government wishes the country to obtain rents from the industry, it will need to impose a tax - and as mentioned above, this may be difficult. In addition, as the market is opened up to more foreign competition, the share of the home airlines will tend to fall, and so will the share of rents.

This will mean that the government will now need to determine the level of competition, not the 'tax rate' as a controlled variable. As competition from overseas increases, (i.e. the route becomes more open), the share of traffic and rents going to the home country, θ , falls. The government is faced with a trade-off - as θ falls the country loses rents, but at the same time p_a falls too, and residents obtain lower cost travel. This is a dilemma often faced by governments. In addition, as θ and p_v fall, benefits from tourism increase. On many routes, additional competition from foreign airlines is an option. This can be modelled by supposing that the government chooses θ , and through it p_a , p_v , and not r (which becomes a function of θ).

This case gives rise to the possibility of a discontinuity, since r can be bounded from below by zero if competition is present. If there are low cost airlines willing to enter the market, the country can ensure that p_a and p_v fall to below that level which would enable the home airline(s) to cover its (their) costs. The country becomes a complete importer of

airline services on the route, and has an interest in ensuring the lowest possible price. The trade-off between airline rents and low prices for residents no longer exists.

This is shown in Figure 1. Curve A shows how airline profits accruing to the country vary as the price of airlines services, P , varies. At \bar{P} , profits are zero. Curve B shows benefits to residents travelling overseas and from home sales to foreign visitors - it is monotonically declining as P rises. Total benefits are shown as Curve C. These reach a maximum at P^* . It is possible that P^* lies to the left of \bar{P} : this would be the case if benefits from tourism were very high, and the only way to have low airline prices involves subsidies to the home airline. (This possibility was considered in Section 3.) If foreign airlines are prepared to compete down prices, such subsidy is not necessary, and the total benefits are shown by curve B up to price P , and then by Curve C beyond. There is a minimum price, \hat{P} , below which airlines will not offer service. It is possible, as shown in Figure 1, that benefits at this price exceed those at P^* . If so, the country can do best by not having an airline and by relying on foreign competition.

The diagram suggests that it is possible to have a quantum jump in aviation policy. It is possible that \hat{P} may be below P^* , yet the country prefers restrictive regulation because it gains profits at the expense of visitors. If \hat{P} falls, it may be worthwhile giving up these profits to get more tourists and the benefits from them. It then switches to a competitive policy and reliance on foreign airlines. Thus Spain realised that it could gain more by having large numbers of tourists carried by cheap foreign charter airlines than it could from profits for its airline, and it allowed easy access to them. Several other countries undoubtedly face this dilemma.

5. The Response Framework

Individual countries cannot simply determine, independently, what prices are to be charged for aviation on routes to other countries. At the least, aviation prices can only be set with the approval of other countries. The analysis so far only indicates the policies countries would like to implement. Countries normally have greater discretion over their tourism tax policies, but if others are perceptive, they may take account of tourism prices in the home country when they determine aviation policies. Nevertheless, there are normally a range of options that a country can choose from when considering its aviation/tourism policy. Countries do have international aviation policies (though sometimes, even the strongest like the US, cannot get their way). (For the Australian Case, see Findlay, 1985.)

Countries' aviation policies exhibit different degrees of "rationality". Sometimes a country will be apparently putting sole or dominant weight on to profits earned by its airline (especially if these profits accrue to the government). In other cases, countries may treat aviation and tourism separately, and maximise net benefits, to consumers and producers, in aviation, but ignore the impacts on tourism. Finally, they may be completely rational, and take account of prices at all levels, and evaluate how they affect net benefits. A country's ability to obtain benefits from aviation and tourism depends on the policies followed by its partner countries.

A fully determinate model of aviation and tourism between two or more countries is unattainable. At the heart of the problem lies a bargaining situation - two countries both seek to increase their share of the benefits available (and the total depends on the policies and shares in place). Thus, a good deal of what happens might best be explained in terms of bargaining models it should be noted that there is no uniquely appropriate model.

It is unrealistic to assume that each country is face with a unique solution on each route. A typical country will find that it has room to move on many or most routes - the question that arises is then one of whether it is maximising its benefits granted the flexibility that it does have. A few possibilities can be considered here.

a) The Constraint Model

A country may find that it can choose the airline profit/tax rate r , or its tourism tax rate t_h , or the overall price to foreign visitors, subject to a constraint. This constraint could be a maximum or minimum. For example, a foreign country may impose a minimum r such that its airline covers costs - it may be willing to allow higher levels of r and θ . Alternatively it may seek to protect its consumers through setting an upper limit on r . If it is rational, it will look to the overall price of tourism, not just the airline price, and the constraint it imposes will be on a combination of t_h , r and θ . One possible level of the constraint is that represented by the status quo. A foreign country may countenance reductions in airline prices or overall trip costs, though not increases. Constraints can easily be handled in the model of Section 3 - the home country maximises subject to the constraints imposed by its partners. There need be no presumption that current policies conform to the constrained optimum.

b) Discrete Options and Continuous Trade-Offs

The foreign country may be willing to agree to a range of policies under which it considers itself equally well off. These policies would involve combinations of the control variables. They might involve a discrete number of combinations, or a continuous trade-off between the variables.

Consider a case of two countries determining an aviation policy. The foreign country may be concerned to achieve a given level of profit for its airline. There are various ways in which it achieves this - as the profit margin, r , falls, a rise in its share $(1-\theta)$ will compensate. The home country is fixed with a trade-off between r and θ - it can maximise subject to this. Effectively, choice of r or θ determines the other, and in the model in Section 3, this can be handled by making one a function of the other. (Analytically, this is identical to the increasing competition model discussed in Section 4). The foreign country is being myopic by looking only at airline profits. If it were 'rational' would look at overall benefits, and the trade-off faced by the home country would involve t_h as well as Q and r . The choice of control variables by the home country to achieve a maximum will result in a Pareto optimum, based on either myopic or 'rational' behaviour of the foreign partner. This approach can be generalised for a number of foreign partners, each of whom, i , insists on particular trade-off between t_h , θ_i and r_i .

c) International Cooperation

A third possibility is that countries cooperate to maximise benefits from tourism and aviation. Prices would then be set equal to marginal costs in each industry, at least under

some world social welfare functions. A simple approach might involve maximisation of the sum of net benefits, perhaps weighted, of the two countries. In the case of cooperation between two countries, the solution may need to be a second-best one, because the policies of, and towards, other countries affect the solution. For example, both countries may tax tourism to gain rents from visitors from other countries. Granted this, the best solution for tourism and aviation between them may be to subsidise aviation (to compensate for the tourism tax which will remain in place).

Such cooperation is not often observed, for a very good reason. It is very likely that the solution does not correspond to the individual maximum for each country. The two countries are cooperating and a Cournot solution will not come about. However each has a monopoly over one of the outputs into trips-tourism services within its borders. It is quite likely that one will be a net exporter and the other a net importer. The former will seek high prices (r , t_a) and the other low prices; they would not both want zero taxes. The analogy is one of a cooperative duopoly for which different prices maximise profits for the different firms.

To achieve the optimum, side payments must be introduced. These rarely take place explicitly, and publicly. However, implicit payments frequently take place. Countries are unable to agree on aviation policies - they resolve the difficulties by making trade-offs in other trade disputes. Thus one country liberalises its approach to aviation when the other allows freer access for the first's agricultural products. Such trade in aviation and non-aviation rights is often regarded with suspicion. However, it may well be, in cases where there is an imbalance between flows of tourism, the only way to achieve an efficient solution is through cooperation.

Overall, a country will be choosing its aviation/tourism policies subject to those of other countries. These will differ, partly because countries differ in the weight they put on different aspects of benefits - airline profits, benefits to home travellers, and benefits from tourism. They differ also because the circumstances of countries differ - the degree of market power they possess in supplying country-specific tourism services, and in the flows of tourism from and to the various partners. A rational country will have different policies for different routes, depending on the circumstances. Thus Britain has a low price policy for UK/Spain routes, on which many British tourists travel, and a higher price policy for UK/Sweden routes, on which relatively few British tourists travel.

6. An Application to Australia

Australia is a country which fits the characteristics of the model - for example, most international travel to and from Australia takes place by air. It is experiencing a tourism boom, several issues related to tourism and aviation are being raised and international aviation policies are being questioned.

Before any policy conclusions can be drawn, it is necessary to quantify the model. This cannot be done here, but for a country such as Australia, it is possible to obtain sufficient information to come to some conclusions as to the relative magnitudes of the key variables, and some policy directions.

The central problem is to work out the benefits and costs of tourism. While much is said about the importance of tourism in Australia, there is little concrete about its benefits or costs (for a theoretical discussion, see Dwyer and Forsyth, 1993a). The problem is to determine what the costs and benefits of an additional tourist (for a period such as a week) are, or what the value to Australia of an additional \$1 spend by a tourist is. To do this, it is necessary to estimate what the impact on tax receipts, government expenditures, private profits and foreign exchange are. This can be done using computable general equilibrium models (see Adams and Parmenter, 1992) The next stage is that of converting effects into measures of benefits. In Dwyer and Forsyth (1993b) a rough attempt is made to measure the benefits of additional tourism in the context of an evaluation of tourism promotion. The main difficulty in this area lies in measuring and valuing externalities which may come about through tourism. This difficulty is not unique to tourism.

It is a relatively straightforward matter to obtain estimates of prices and profits on air routes. While route by route data cost are not available, it is possible to develop estimates which are probably sufficiently accurate for the purposes here. (See Findlay, 1985, Ch. 6.) Estimates exist of tourism and air fare elasticities for various major destinations and sources of tourists. (Bureau of Transport and Communication Economics, 1988.) Cross-elasticities are harder to come by. The problem with elasticity estimates is that they are, of their nature, not highly reliable. Data on tourism flows are readily available. While simple characteristics of the aviation/tourism policies of other countries are not easy to develop, in analysing the options for Australia it is possible to outline the policies for the major trading partners (eg, NZ, the US and Japan). It is then possible to specify the options open to Australia. Models of the aviation sector have been developed; see Centre for International Economics, 1988 and Productivity Commission, 1998 for Australia and Gillen et al, 1997, for a Canadian model.

The information is available to make the model operational for Australia; indeed the aviation side has been modelled. Estimates for the first part - what Australia gains from tourism - would be interesting on their own. They could be used to examine how aviation policies towards particular countries should be framed. General policies towards tourism and aviation could be evaluated in the light of the model. There are many questions that might be examined, but some of particular interest are as follows:

- a) How liberal should Australian aviation policy be? Should it accept a lessened role for the national carrier, in return for lower fares and more tourists? This would involve a lessened opportunity to profit from aviation, but an increased opportunity to gain from tourism, and it would mean greater benefits for residents who travel overseas. For nearly two decades Australia has faced this question, as competition from Asian carriers grew, as charter airlines sought to enter the market, and as the US sought to increase competition on the Pacific route.
- b) What would be the implications of liberal aviation agreements with particular countries? Suppose Australia and Japan were to form a unified market for air transport. Would a deregulated market be the best solution, granted any distortions and externalities present in their tourism sectors? How might the implications for other routes be assessed?

- c) Should Australia have a unified aviation policy, whether restrictive or liberal, to be applied to all countries, or should it tailor its approach to particular countries? Thus it can have a restrictive approach to Japan, but a liberal approach to the UK, as it does, more or less, at present. It is possible to use the model to examine this question by looking at the flows of visitors to and from Australia, the benefits from tourism, and thus the approach to airline pricing which most advances Australia's interest – this determines how liberal it should be. In principle, discrimination is desirable if it is possible, but it may turn out that the benefits do not justify the effort.
- d) Does Australia gain from current aviation pricing arrangements? On major routes, prices are set by the airlines on trips from Australia, but often by other governments on trips to Australia. Trip prices can differ substantially. When fares to Australia are high, tourism to Australia is discouraged, though Australian residents enjoy lower fares. Would it be in Australia's interest to pursue more equal fares?
- e) To what extent should Australia encourage international tourism? Currently it has an explicit policy of promoting tourism, and currently it spends a lot to this end. State governments also spend on tourism promotion. Tourism can also be encouraged by differential tax treatment. Tourism may generate positive externalities, profits and taxes. In addition, aviation policies with particular countries (eg with Japan) may be regarded as too restrictive to generate maximum benefit to Australia. If so, tourism might well be worth promoting and subsidising. Currently, Australia does not know if its interests are best served by taxing or subsidising tourism, or neither of these.
- f) Changes in tax structures affect tourism and aviation. A move from direct towards indirect taxes, eg towards a VAT, would result in tourists paying higher prices. The benefit for Australia of an additional \$1 spent by foreign tourists would increase. Aviation prices and profits might be reduced if overall benefits to Australia are to be maximised. Alternatively, would it be in Australia's interest to grant exemptions from a VAT for foreign tourists?
- g) State governments have seen the tourism boom, and have sought to gain from this boom. NSW recently imposed an accommodation tax in Sydney, the main visitor destination. Would the country as a whole gain from higher tourism taxation?

7. Concluding Remarks: Market Power and World Welfare

This paper concentrates on the links between tourism and international aviation. The two are viewed as jointly consumed services. The question is raised of how an individual country might be about making the most of its participation in tourism and aviation. A country will possess a degree of market power over the attractions it encompasses, and it can use this power to extract profits or taxes at either or both the levels of tourism and aviation. It is constrained, and whatever level it chooses to tax at, there will be undesirable consequences, such as losses of benefits incurred by home tourists or residents travelling abroad. The model shows how it might choose taxes (or policies)

which make the most of its possibilities, and which take account of the linkages and distortions present.

Actual results, such as prices of international aviation, do not depend solely on one country; they are the result of the interaction of many. As a first stage, it is necessary to show how an individual country might make its choices. It is possible to allow for some patterns of response by other countries, and while a country does not have complete freedom over what it does, it will often have some latitude. The question of what are the best tourism and aviation policies often to a country are important practical ones which have not often been rigorously analysed together..

A model such as this suggests what should be looked for when policies are being formulated. As a first step, it is essential to put some measure on the benefits and costs of tourism. It is not difficult to derive approximate orders of magnitude, but this is rarely done. It is more difficult to come across reliable estimates of other relevant parameters, such as own and cross price elasticities of tourism demand. Once this is done, it is possible to put the pieces together, to come to some quantitative conclusions as to what policies might make the most out of tourism and aviation.

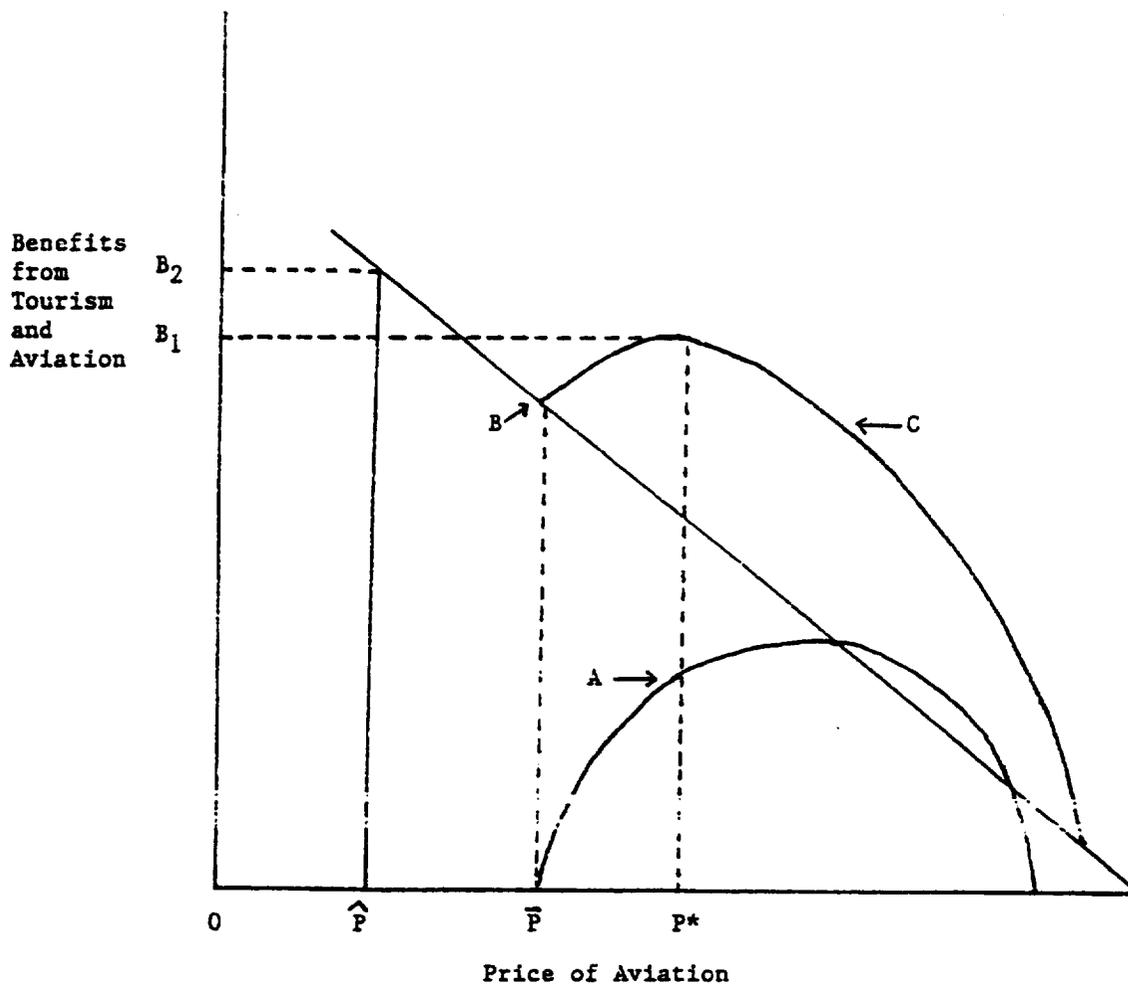
Until now most the policy activity has been at the aviation level. Aviation policy is often analysed quite separately from tourism. Under special circumstances, this will be sufficient, but it is much more likely that the tourism consequences of aviation policy will be important, and it is quite conceivable that any gains or losses through tourism of an aviation policy change will outweigh the direct gains and losses at the aviation level. Even if there is to be no explicit policy towards tourism, if an efficient policy is to be formulated, it is necessary that views about the costs and benefits of tourism, and the various links between the two industries, be made explicit and incorporated.

The models discussed indicate the interest of individual countries in exercising their market power. They are constrained to an extent by their partners in the case of aviation, but are rather less constrained with tourism taxation. Countries are able to extract rents from aviation if their partners acquiesce. This is possible because not all countries have the same maximand, and some wish to protect their airlines. Overall world welfare would be maximised by a move to a more liberal environment, with prices at cost and a reliance on trade to ensure that services are provided at minimum cost. In many trading situations, a move towards liberalisation involves countries removing protection which creates costs that primarily fall on themselves. In the case of aviation and tourism, countries possess market power, and have got used to using it. Some countries will resist a move towards liberalisation because they gain from a more restricted environment. Their airlines profit from higher fares charged to non residents. Thus purely aviation negotiations will be insufficient to achieve a liberal environment; to achieve liberalisation, non aviation trade offs will need to be included.

With aviation, there can be pressures from a country's partners to liberalise; with tourism there is rather less pressure, because no one country suffers much from another's tourism policies. For the most part, countries are price takers of tourism goods and services. Any taxes are spread amongst tourists from many countries and it is not worth any one country retaliating. Countries are able to gain from essentially levying optimal tariffs on tourism. As aviation liberalisation proceeds, and tourism grows, countries are showing

more interest in increasing their rents at the tourism level, for example, by levying specific tourism taxes. While currently less of a distortion than airlines regulation, these distortions appear to be growing. It has been difficult enough to lessen distortions at the aviation level; it will be even more difficult to remove distortions at the tourism level, and enable free trade in tourism as well as aviation.

Figure 1



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**A PRELIMINARY ASSESSMENT OF THE 1995 CANADA-U.S. TRANSBORDER
AIR SERVICES AGREEMENT**

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1 INTRODUCTION

While trade in most goods and services between the United States and Canada is generally open, such was not the case for transborder airline services for most of the post-war period. Indeed, for almost three decades the accord governing Canada-U.S. airline services was among the most restrictive of all such pacts entered into by the United States. At the 1985 Shamrock Summit, Prime Minister Mulroney and President Reagan recognized the inappropriateness of that state of affairs and that promotion of transborder air travel should be encouraged. Yet it took the two nations a decade to remedy the problem; only in February 1995 did they sign a new air services agreement (ASA) that significantly liberalized trade in airline services between them.

The purpose of this paper is to explore the impact of the February 1995 ASA on the market for transborder airline services. This issue is of particular importance because past regulatory policies have affected the ability of individual carriers to benefit from the new ASA. As a result, the likelihood that competition in certain markets could be hindered is a real concern. To assess these effects, the paper begins by reviewing the domestic, international, and transborder aviation policies of the two countries. After discussing the provisions of the new ASA, it then examines its impact on competition and concentration in transborder air services market.

2 AVIATION POLICES OF THE TWO COUNTRIES

The ability of Canadian and U.S. carriers to respond to the new opportunities created by the February 1995 air services agreement has been shaped by their countries' prior aviation policies. Consider first the domestic aviation policies of the two countries. The modern era of U.S. domestic aviation began in 1938 with the creation of the Civil Aeronautics Board. For the next forty years the CAB maintained tight controls over entry, exit, and pricing in domestic markets. Most of the industry's output was supplied by twenty or so carriers. On most major domestic routes two or three carriers typically provided service. In 1978, the regulatory regime underwent substantial modification with the passage of the Airline Deregulation Act, and the CAB itself ceased to exist after 1984. As a result of domestic deregulation, carriers are now free to enter and exit markets and to price their services as they see fit. The experience has generally been a positive one: new carriers have entered the industry, inflation-adjusted prices have fallen, and flight frequencies and passenger traffic have risen. Although industry concentration (measured by the four-firm concentration ratio) has risen above its pre-deregulation level, concentration on individual routes has fallen. The number of major players in the U.S. airline industry remains large by Canadian standards: American, United, Delta, Northwest, US Air, Continental, TWA, and Southwest have extensive systems and compete with one another on a nation-wide basis. With the exception of Southwest, all of these carriers have developed large, complex hub-and-spoke operations which serve both domestic and international markets. A seemingly constant flow of new entrants, most of which have focused on providing low-cost service, have pressured the larger players to keep their costs and prices under control.

Canadian domestic aviation policy has undergone a similar transformation. Federal regulation of domestic air services commenced in Canada with the passage of the Transport Act of 1938.

Governmental policy focused on creating a national network of routes. To cross-subsidize unprofitable services, regulators established route monopolies in profitable markets. Under this and successive legislation, Air Canada enjoyed a protected and favored position in many key markets. However, in 1984 the government of Canada began to relax its regulation of domestic airline service. The ensuing regulatory reforms divided the country into two zones, northern and southern. Existing regulations in the northern, less populated zone remained intact, as the area's thin population was believed to be unable to support competition. Most regulatory controls on airline service were removed in the south, including restrictions on capacity, frequency of service, and equipment type. Carriers were also granted power to reduce prices as they saw fit, while their ability to raise prices automatically was limited by an inflation index. Unlike the U.S. experience, however, the overall domestic market and individual city-pair markets remained highly concentrated after deregulation. The industry's concentration increased in the late 1980s, with the establishment of Canadian Airlines International Limited (CAIL), a new carrier created from the consolidation and merger of the operations of CP Air, Wardair, and four regional airlines--EPA, Quebecair, Nordair, and PWA. Most remaining regional carriers act as feeders either to CAIL or Air Canada. Air Canada and CAIL are essentially a duopoly, controlling directly or through their affiliates almost all domestic traffic.

These differences in the structure of the two countries' domestic airline industries have created substantive differences in their international aviation policies. U.S. policy has generally favored open competition in international airline markets, in part because U.S. policymakers believe that U.S. flag carriers would dominate the world market and in part because they must accommodate the desires of numerous carriers to provide international services. Conversely, Canada's international aviation policies initially were strongly influenced by Air Canada's status as a Crown Corporation. Air Canada enjoyed a monopoly on all Canadian flag international routes from 1937 to 1948, when CP Air was designated as the nation's flag carrier in the Pacific. Beginning in 1965, Canada adopted a "division of the world policy," granting each carrier exclusive regional spheres of influence. This approach was modified in 1987 when the Minister of Transportation reallocated international operating authority between CP Air and Air Canada. Rather than grant exclusive rights to serve regions, the two carriers were given exclusive rights to serve individual countries within these regions. Wardair's entry into the transatlantic market and its subsequent purchase by CAIL eroded the boundary lines established in the 1987 order. As a result, both CAIL and Air Canada may provide service to London, Frankfurt, and Paris. While Canada has negotiated the right to designate multiple carriers in 39 of the 61 ASAs it has signed, it has exercised this right only in a few cases (Oum and Taylor, 1995).

These domestic and international policies in turn affected the transborder market. The basic ASA governing transborder air services was signed in 1966, although it has subsequently been amended several times. As amended, the 1966 ASA delineated 83 separate point-to-point routes between the two countries. Only 19 of these routes--so-called "double track routes"--were open to competition between carriers of the two nations. Thirty-eight of the routes were reserved for U.S. carriers and the remaining 26 were limited to Canadian airlines (Lewis, 1995). On most of these routes, each nation could designate more than one airline only with the permission of the other government. While capacity was left to the determination of the

designated carriers, either government was allowed to reject proposed fares on transborder routes.

The United States allocated its transborder rights resulting from the 1966 pact among a handful of firms. These route allocations reflected the then existing state of the U.S. airline industry. Delta, for example, obtained transborder rights between Toronto and Pittsburgh but not between Toronto and Atlanta. Air Canada possessed a Canadian-flag monopoly on all transborder routes until 1967, when CP Air received its first U.S.-Canada route, between San Francisco and Vancouver. However, most of the routes authorized by the 1966 ASA as amended were allocated to Air Canada. Thus CP Air, and its corporate successor, Canadian Airlines, had little opportunity to expand its transborder service under the 1966 ASA.

As part of the Shamrock Summit Declaration in March 1985, both countries promised to examine the possibility of creating free trade in transborder aviation services. Neither side liked the 1966 ASA, for its anti-competitive philosophy ran contrary to the aviation policies of both countries. Both sides agreed that it was suppressing transborder travel and economic activities between the two nations. For example, between 1980 and 1993, transborder air travel grew only 1.8 percent annually, well below growth rates experienced in country-pairs involving their other leading trading partners. Community groups on each side of the border--particularly representatives of local airports, the United States Airports for Better International Air Service (USA-BIAS) coalition and Association of Canadian Airport Communities (ACAC)--complained bitterly that the existing ASA was hindering economic development of their areas (Kaduck, 1996).

While both stood to gain opportunities to enter new transborder markets, the interests of Canada's two primary flag carriers in the creation of a new, liberal ASA were asymmetric. Air Canada had a strong position in the transborder market under the old ASA, while Canadian Airlines had a very weak one. Should a liberal ASA be signed, Canadian Airlines had little existing market share to lose; the reverse was true for Air Canada. The flip side of this asymmetrical position was that when the new ASA was signed in February 1995, Canadian Airlines was in a far weaker position to exploit the agreement than Air Canada. It was but a minor player in the transborder market, serving a handful of U.S. west coast cities (San Francisco, Los Angeles, and Honolulu). Air Canada had a far greater physical presence (i.e., gates, check-in terminals, etc.) and brand name recognition in most U.S. cities than Canadian Airlines.

3 THE 1995 TRANSBORDER AIR SERVICES AGREEMENT

As a result of these pressures, the United States and Canada agreed to a new, much liberalized ASA in February 1995. The new ASA allows each country to designate as many carriers as it wishes to provide transborder services. Neither country may unilaterally limit the capacity offered by any of these carriers. Carriers are free to charge any prices they wish; such prices remain in effect unless both governments disapprove of them. The grounds for disapproval are limited to preventing unreasonable discrimination or exploitation of a dominant position (fares too high) and protecting carriers from competing against low fares resulting from government subsidies or from low fares designed to eliminate competition. Canadian carriers were given

access to scarce slots at LaGuardia and O'Hare and allowed to purchase slots at Washington National airport (Lewis, 1996). The pact offers the Canadian carriers a head start, as they are immediately free to fly between any U.S. and any Canadian city of their choice. While similar rights were ultimately granted to U.S. airlines, in the short run their ability to serve Vancouver and Montreal was constrained for two years and for three years at Toronto. During the each year of these phase-in periods, the U.S. government was allowed to designate a limited number of carriers to provide new transborder service to Montreal, Toronto, and Vancouver (MTV). In general, the U.S. government allocated these rights to carriers to fly between their U.S. hubs and the MTV airports. As the transition period has expired, U.S. carriers are now able to offer whatever services they wish to any Canadian city they choose.

4 THE IMPACT OF THE NEW ASA ON COMPETITION

The impact of the new ASA between the United States and Canada on competition and concentration in the transborder market will be assessed using three definitions of the relevant market:

- * the entire transborder market
- * transborder service at individual airports
- * service in individual transborder city-pair markets

We first will analyze whether competition and concentration in air services between the United States and Canada has increased or decreased considering the transborder market in its entirety. Table 1 depicts the number of weekly, non-stop transborder flights using jet aircraft offered by individual carriers at three points in time: January 1995, i.e., just prior to the February 1995 signing of the new transborder air services agreement; January 1996, approximately ten months after the agreement was implemented; and January 1997, twenty-two months later. Note that during this time period Canadian carriers were free to enter all transborder markets, while the phase-in restrictions were in effect on U.S.-flag service to the MTV airports. Note also that Table 1 utilizes flight share--the percentage of flights offered by an individual carrier relative to the total number of flights offered in the market--to measure the extent of competition and concentration. This is not a perfect measure of market power, because it is an input measure rather than an output measure. However, previous studies have shown that there is a high correlation between flight share and market share. Because timely flight share data are readily available from such sources as the *Official Airline Guide* while passenger share data are not, flight share data will be used.

As Table 1 indicates, Air Canada has been the dominant carrier in the transborder market, and its dominance increased during the time period shown in Table 1. In January 1995, it offered 33.7 percent of all flights between Canada and the United States. As a result of the new ASA and the restricted entry status of the MTV airports, Air Canada increased its dominance. Air Canada accounted for 53 percent of the increase in transborder flights attributable to the new ASA, raising its flight share in the market to 40.0 percent. Delta, the second-most important carrier in the transborder market under the old ASA, retained that status. Despite a 12 percent increase in its flight offerings from January 1995 to January 1997, Delta's share of transborder flights fell from 18.8 percent to 14.3 percent.

The information presented in Table 1 can be used to calculate changes in concentration. Concentration can be measured in several ways. The simplest measure is the four-firm concentration ratio: the percentage of market output attributable to the four largest firms in that market. By this measure, concentration in the transborder market declined over the time period depicted in Table 1, falling from 80.6 percent in January 1995 to 75.1 percent in January 1997. However, aggregating the market shares of the four largest carriers masks the rapid increase in Air Canada's market share with the declines of those of Delta, American, and US Air. A second, more complicated measure of concentration is the Herfindahl-Hirschman Index (HHI), which is the sum of the squares of individual carrier market shares. The HHI of a perfect monopoly would be 10,000; a perfectly competitive industry would have an HHI approaching 0. The primary advantage of the HHI is that it is more sensitive to the size distribution of firms than the four-firm concentration ratio is. The U.S. Department of Justice's merger guidelines suggest that an HHI over 1000 may raise antitrust concerns. As Table 1 indicates, the HHI of the transborder market rose from 2017 to 2161 from January 1995 to January 1997, suggesting that the market was highly concentrated to begin with and that has become more concentrated as a result of the new ASA. Whether this is a temporary condition attributable to the MTV phase-in provisions or a permanent one resulting from the head start given Canadian flag carriers is a question worthy of scrutiny over the next several years.

We next consider the second market definition, transborder service at individual airports. Post-deregulation, most U.S. carriers have focused on developing hubbing complexes, and most new routes added by individual carriers represent additional spokes at those hubs. Existing studies suggest that carriers have exploited the monopoly power that they have developed at these hubbing complexes by raising prices, particularly in city-pairs involving the hubs of two carriers. Accordingly, it seems reasonable to see how the 1995 ASA has affected competition and concentration of transborder services at individual airports.

Table 2 reports the number of weekly nonstop transborder flights offered by individual carriers using jet aircraft at Toronto; all of these flights served Pearson Airport. As the table reports, in January 1995, carriers offered 620 weekly nonstop transborder flights. Air Canada was the largest carrier in the market, offering 251, or 40 percent of the flights. The next largest carrier was American, with 122, or 20 percent of the flights. Both Canadian Airlines and Air Canada took advantage of the temporary constraints imposed on new services to Toronto by U.S. carriers. By January 1997, Air Canada had more than doubled its service to Toronto, while Canadian Airlines added over 60 new flights. Air Canada's share of the flights offered at Pearson rose to 52 percent, while that of the second most important carrier, American, fell to 12 percent. The four-firm concentration ratio for transborder service at Toronto fell from 86.9 percent in January 1995 to 81.0 percent in January 1997; however, its HHI rose from 2461 to 3124 during this period.

Table 3 presents similar data for Montreal. As was the case with Toronto, all of the transborder services reported in this table are to a single airport (Dorval). As a result of the new ASA, Montreal has experienced a 27 percent increase in transborder service, from 326 weekly flights in January 1995 to 414 flights in January 1997. Air Canada offered the most service to Montreal under the old ASA. Although it added 24 weekly flights, its flight share in this market fell slightly, from 38 percent in January 1995 to 36 percent in January 1997. Delta

Airlines, the second largest carrier in the market under the old ASA, retained this position. It expanded its services to Montreal more than any other carrier except Air Canada, although its flight share has also declined modestly (from 28 percent to 27 percent). Accordingly, while Montreal has had a significant increase in new service subsequent to the implementation of the new ASA, concentration of service at that city has declined. The four-firm concentration ratio for transborder flights serving Montreal fell from 89.6 percent in January 1995 to 85.7 percent in January 1997, while the HHI fell from 2633 to 2385 during this span of time.

The third of the MTV cities, Vancouver, presents a picture similar to Montreal, as is shown in Table 4. New services to Vancouver increased 70 percent from January 1995 to January 1997. Canadian Airlines maintained its status as the largest provider of service at the city, although its service rose only modestly, from 61 weekly flights in January 1995 to 72 weekly flights in January 1997. Its share of flights fell from 37 percent in January 1995 to 26 percent in January 1997. United retained its position as the second largest provider of transborder services to Vancouver, although its share of transborder flights also fell during this period. Vancouver, however, is unique in two regards. First, it is the only airport where the presence of both Canadian flag carriers is somewhat in balance. This is due Air Canada's taking advantage of the new ASA to add services freely, while Canadian Airlines failed to aggressively exploit its first-mover advantages at Vancouver, no doubt due to its extremely weak financial state in the 1990s. Second, the cumulative addition of new services by small U.S. carriers is quite noticeable, accounting for 55 flights in January 1997, which is almost half of the total increase in new services from January 1995 to January 1997. Accordingly, at this airport concentration has declined as is indicated by a decrease in the four-firm concentration ratio (from 91.6 percent to 65.5 percent) and in the HHI (from 2471 to 1552) during the two year period depicted in the table. Services at other Canadian cities, including Calgary, Regina, Winnipeg, Ottawa, Halifax, and Saskatoon have increased more modestly than at Vancouver, although in the interest of space we will not provide comparable tables for these cities.

We next consider the third market definition, transborder service in individual city-pair markets. Table 5 reports the number of carriers serving the twenty most important transborder markets, as well as their HHI for the three study dates. In only a few of these markets has there been new entry; in those markets where entry has occurred, the HHI remained quite high. This lack of entry is attributable to two institutional factors. First, 19 of these 20 city-pairs involve the MTV cities; the ability of U.S. carriers to enter MTV transborder markets was restricted during the time period under study. Second, most of the limited rights granted to U.S. carriers to enter MTV markets were allocated to brand new services from their hubs, not to these Top Twenty markets.

5 CONCLUSIONS

Despite the dramatic changes wrought by the 1995 ASA, levels of concentration remain quite high in the transborder market, regardless of the market definition or the measure of concentration used. There has been some diminution of concentration in several markets, most noticeably those involving Vancouver. Despite the high levels of concentration observed in Tables 1 through 5, one must remember the starting point. Competition under the transborder agreement in existence prior to February 1995 was extremely limited. The number of city-

pairs provided service reflected the patterns of commerce between Canada and the United States circa 1966, and only a handful of these city-pairs received any competitive service. At the key transborder airport of Toronto, Air Canada aggressively took advantage of the phase-in period to strengthen its position there. However, Air Canada's domination of Toronto is no higher than that of many U.S. carriers at their domestic hubs. In short, despite the high levels of observed concentration two years after the signing of the new transborder air services agreement, transborder travelers are still better off with this agreement than without it, given the paucity of transborder services in many important North American city-pairs prior to February 1995.

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Table 1
Total Weekly Transborder Flights, by Carrier

	Total flights			Share of Transborder Flights (in percentage points)		
	Jan-95	Jan-96	Jan-97	Jan-95	Jan-96	Jan-97
Air Canada	464	772	811	33.7	40.2	40.0
Canadian Airlines	66	177	145	4.8	9.2	7.1
American	205	241	236	14.9	12.5	11.6
United	91	119	98	6.6	6.2	4.8
Delta	258	203	290	18.8	10.6	14.3
Northwest	110	145	187	8.0	7.5	9.2
US Air	181	169	145	13.2	8.8	7.1
Continental		14	28	0.0	0.7	1.4
Alaska		54	48	0.0	2.8	2.4
All other		27	40	0.0	1.4	2.0
Total	1375	1921	2028	100.0	100.0	100.0
Canadian flag	530	949	956	38.5	49.4	47.1
US flag	845	972	1072	61.5	50.6	52.9
Four firm conc ratio	80.6%	72.5%	75.1%			
HHI	2017	2152	2161			

Table 2

**Total Weekly Transborder Flights
to Toronto**

	Jan-95	Jan-96	Jan-97
Air Canada	251	434	531
Canadian Airlines	5	86	69
American Airlines	122	123	124
United Airlines	42	35	42
Delta Airlines	83	21	96
Northwest Airlines	34	0	41
US Air	83	81	70
Continental Airlines	0	0	14
Alaska Airlines			
All other	0	13	26
Total	620	793	1013
Four firm concentration ratio	86.9%	91.2%	81.0%
HHI Index	2461	3487	3124

Table 3
Total Weekly Transborder Flights
to Montreal

	Jan-95	Jan-96	Jan-97
Air Canada	125	167	149
Canadian Airlines			
American Airlines	34	41	42
United Airlines			
Delta Airlines	91	112	110
Northwest Airlines	34	34	48
US Air	42	47	48
Continental Airlines		14	14
Alaska Airlines			
All other			3
Total	326	415	414
Four firm concentration ratio	89.6%	88.4%	85.7%
HHI	2633	2652	2385

Table 4
Total Weekly Transborder Flights
to Vancouver

	Jan-95	Jan-96	Jan-97
Air Canada		49	35
Canadian Airlines	61	78	72
American Airlines	21	14	28
United Airlines	35	63	42
Delta Airlines	35	49	35
Northwest Airlines	14	14	14
US Air			
Continental Airlines			
Alaska Airlines		14	14
All other		14	41
Total	166	295	281
Four firm concentration ratio	91.6%	81.0%	65.5%
HHI	2471	1797	1552

Table 5
Characteristics of Twenty Largest Transborder Market

		Number of Competitors			Hirschman-Herfindahl Index		
		Jan-95	Jan-96	Jan-97	Jan-95	Jan-96	Jan-97
Toronto	New York	2	3	3	5008	4482	4329
Toronto	Chicago	3	3	4	3363	3378	2662
Montreal	New York	2	4	4	5284	3879	3928
Toronto	Los Angeles	1	1	1	10000	10000	10000
Toronto	Miami	2	3	2	6867	5083	5346
Vancouv	Los Angeles	2	3	5	5102	3795	2395
Toronto	Boston	2	2	2	5184	5184	6574
Toronto	Tampa/St. Pet	2	3	2	5000	3600	6800
Toronto	San Francisco	2	2	2	6250	6250	6250
Montreal	Miami	2	0	2	5022	n.a	5000
Vancouv	San Francisco	2	4	3	6159	2649	3333
Calgary	Los Angeles	2	2	2	5555	5000	5000
Montreal	Chicago	2	2	2	5400	5095	5439
Montreal	Los Angeles	1	1	1	10000	10000	10000
Toronto	Philadelphia	1	2	2	10000	5007	5016
Montreal	Boston	2	2	2	5002	5555	5312
Toronto	Dallas/FW	1	1	1	10000	10000	10000
Toronto	Atlanta	0	1	2	n.a	10000	5398
Toronto	Honolulu	1	2	2	10000	6701	7812
Toronto	Detroit	1	1	1	10000	10000	10000

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An Analysis of Profitability of the World's Major Airlines

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ABSTRACT: Airline profitability depends on airlines' cost competitiveness and their ability to price above costs. And the ability to set prices above cost depends on market power and the firm's ability to make use of innovative pricing techniques and market information. In the past, some carriers have been profitable without being cost competitive because they were able to charge exorbitant prices to consumers. Increased competition in the international air transport markets have put pressures on carriers' ability to raise prices. At the same time, input prices have been increasing continuously. To counter-act such trends, airlines have made tremendous efforts to improve efficiency and productivity in order to cut cost. Using a yearly panel of 22 major airlines over the 1986-95 period, this paper examines airlines' profitability changes by examining changes in productivity and their ability to price above cost. The study found that European and Asian carriers consistently improved productivity throughout the period even during the time of rising profitability, achieving higher productivity growth than North American carriers. However, European and Asian carriers experienced much faster decline in price recovery ability than North American carriers, because their input prices have increased rapidly and airfares have declined under the pressures of increased competition. Overall, airline profitability have improved during the 1990s.

INTRODUCTION

International skies have been substantially liberalized since the early 1980s. Like many other industries, the international airline industry is becoming increasingly exposed to the pressures of the market-place as deregulation and liberalization processes advance. Increased competition generally has two conflicting effects on the firms: it creates downward pressures on output prices, and it creates incentives for improving

productivity and efficiency (Spence, 1986). In the international air transport market, the increased competition (together with increasing input prices) has in many cases led to decline in firm profits, as carriers' monopoly positions are challenged. Profitability is an important factor contributing to airlines' survival. Many airlines have been forced to undertake major restructuring in order to reverse the declining profit by improving productivity and efficiency.

A number of studies, such as Bailey, Graham, and Kaplan (1985), Morrison and Winston (1986, 1995), Bruning and Hu (1988), and Antoniou (1992), have addressed the issue of airline profitability. These studies either posit possible relationships between profitability and a number of potential pertinent variables, or test such relationships through regression analysis. In this study, we take a somewhat different approach to examine the underlying dimensions of airline profitability. In particular, the American Productivity Center (APC) model is used to decompose changes in airline profitability into two components capturing changes in productivity and price recovery ability (Miller, 1984, Banker, Chang, and Majumdar, 1993, 1996). The APC model is gross-profit oriented and focuses on total factor productivity. Profitability is defined as the function of productivity and price recovery.

The paper is organized as follows: Section 2 describe the APC model; Section 3 briefly describes the sample airlines and the data; the APC model is applied to explain changes in the performance of the world's 22 major airlines in Section 4; Section 5 contains a summary and concluding remarks.

THE APC MODEL

The APC model is based on actual quantities and prices of outputs and inputs over a period of time. Changes in profitability are defined as the product of changes in productivity and changes in price recovery. The total dollar effects of both productivity and price recovery are used to explain changes in profitability from one period to another. For outputs and inputs, dollar values are determined by multiplying a physical quantity by unit price. Change in profitability is measured by the comparison between relative changes in values of outputs and inputs.

A profitability change ratio is defined as the ratio of profitability for period t to profitability for base period 0. It can be expressed as:

$$lity(PFTBLT) = \frac{\pi^t}{\pi^0} = \frac{p^t y^t / w^t x^t}{p^0 y^0 / w^0 x^0} \quad (1)$$

where

y^t is the output quantity at period t , $t = 0, 1, 2, \dots, T$
 p^t is the price per unit of output at period t , $t = 0, 1, 2, \dots, T$
 x^t is the input quantity at period t , $t = 0, 1, 2, \dots, T$
 w^t is the price per unit of input at period t , $t = 0, 1, 2, \dots, T$
 $t = 0$ is the base period.

This profitability change ratio can be decomposed into changes in productivity and changes in price recovery. The APC productivity change ratio (APRDT) is the ratio of the values of current period outputs to base period outputs, divided by the ratio of the values of current period inputs to base period inputs. It is expressed:

$$APRDT = \frac{p^0 y^t / p^0 y^0}{w^t x^t / w^t x^0} \quad (2)$$

Equation (2) holds output prices constant at base period levels while capturing changes in output quantities, and holds input prices constant at current period levels while capturing changes in input quantities.

The APC price recovery ratio (APRCR) is the ratio of value of outputs at current period prices to the value at base period prices, divided by the ratio of the value of inputs at current period prices to the value at base period prices. It is expressed:

$$APRCR = \frac{p^t y^t / p^0 y^t}{w^t x^0 / w^0 x^0} \quad (3)$$

Equation (3) holds output constant at current period level while output prices are allowed to vary, and inputs are held constant at base period level while input prices vary.

Equation (1) is the product of equations (2) and (3). Improvement in productivity performance and/or price recovery ability will lead to improvement in profitability. This decomposition is useful for identifying to what extent the change in profitability is influenced by changes in output and input prices and by changes in productivity.

SAMPLE AIRLINES AND THE DATA

Sample Airlines

The selected airlines are all international carriers, and have significant involvement in scheduled passenger services. Some of the airlines are 100 percent state owned, some are private companies, while others have mixed ownership. For example, Air France, Iberia and Thai

International are government owned, while the US carriers are all private companies.

Exhibit 1 provides some recent descriptive statistics of the airlines¹. The size of the airlines, as measured by revenue tonne-kilometres (RTK) in 1995, ranges from 2.2 billion RTK for Scandinavian Airlines Systems (SAS), to 19.6 billion RTK for United Airlines. In terms of number of passengers carried in 1995, it ranges from 8.3 million (8.6 million in 1996) for Canadian Airlines International (CAI), to 87 million (97 million in 1996) for Delta.

Aside from US carriers, most of the sample airlines provide mainly international services, some do not provide domestic services at all. Qantas, Singapore Airlines (SIA), Cathay Pacific and Japan Airlines (JAL) serve mostly inter-continental traffic, while US Air and SAS have a large proportion of their business in domestic or intra-continental traffic.

Profitability performance varies greatly among the sample airlines. British Airways, SIA and Northwest Airlines were the most profitable in 1995, with net income of US\$740 million, US\$622 million (US\$624 million in 1996), and US\$ 506 million (US\$536 million in 1996), respectively. Air France suffered the biggest loss, a net loss of US\$581 million, in 1995. Iberia and Canadian Airlines International (CAI) also suffered losses in 1995, at a net loss of US\$361 million and US\$143 million (US\$137 million in 1996), respectively. CAI is the only airline in our sample that incurred an operating loss² in 1995. All of the Asian carriers were able to achieve a positive net income in 1995.

Data Sources

A panel of 22 airlines over the 1986-1995 period forms the primary data base for this study. The annual data were compiled mainly from Digest of Statistics published by the International Civil Aviation Organization (ICAO), in particular, the annual series on Traffic, Fleet-Personnel, and Financial Data. Additional data were obtained directly from airline companies, airlines' annual reports, the Airline Monitor, IATA publications, Statistics Canada publications, and other sources.

Outputs

Five categories of airline outputs are considered: scheduled passenger service (measured in revenue tonne kilometres or RTK), scheduled freight service (measured in RTK), mail service (measured in RTK), non scheduled services (measured in RTK), and incidental services (non airline businesses). Incidental services include a wide variety of non airline businesses such as catering services, ground handling, aircraft

maintenance and reservation services for other airlines, sales of technology, consulting services, and hotel business.

A quantity index is constructed for the incidental output in order to include the incidental services in our analysis. The index is computed by deflating the incidental revenues by a general price index constructed using the Purchasing Power Parity (PPP) index for GDP obtained from the Penn World Table (Summers and Heston, 1991) and U.S. GDP deflator. The PPP index adjusts for changes in market exchange rates and changes in real price levels of various countries relative to the U.S., and the US GDP deflator ensures that the quantity index is comparable over time.

A multilateral output index was formed by aggregating the five categories of outputs using the multilateral index procedure proposed by Caves, Christensen, and Diewert (1982). Output price was then computed by dividing total revenues by the aggregate output index.

Inputs

We distinguish five categories of input: labour, fuel, materials, flight equipment, and ground property and equipment (GPE). Labour input is measured by total number of employees. Fuel input is measured in gallons of fuel consumed. For flight equipment, a fleet quantity index is constructed by aggregating different types of aircraft using the translog multilateral index procedure proposed by Caves, Christensen, and Diewert (1982). The leasing price series³ for these aircraft types are used as the weights for aggregation. The annual cost for each aircraft type is estimated by the product of the lease price and the number of airplanes. Total annualized aircraft cost is then computed as the sum across all categories of aircraft. The real stock of ground properties and equipment (GPE) is estimated using the perpetual inventory method. Under the assumption that the flow of capital service is proportional to the capital stock, the annual cost of using GPE is computed by multiplying the real GPE stock by a GPE service price. The GPE service price is constructed using the method proposed by Christensen and Jorgenson (1969) which accounts for interest, depreciation, corporate income and property taxes, and capital gains or losses. Since the GPE costs are small relative to the costs of flight equipment, these two categories of capital inputs are further aggregated into a single capital stock series using the translog multilateral index procedure. The materials input contains all other inputs, not included in any of the input categories discussed above (labour, fuel, and capital). As such, materials cost is the catch-all cost category, and thus includes numerous items including airport fees, sales commissions, passenger meals, employee travel, consultants, non-labour repair and maintenance expenses, stationery,

and other purchased goods and services. The materials cost is computed by subtracting labour, fuel and capital input costs from the total operating cost reported in ICAO's Financial Data. As in the case of incidental output, it is necessary to construct a materials quantity index in order to include the materials input in our analysis. Since the materials cost also includes numerous items and activities, the same general price index is used to deflate the materials cost to compute the materials quantity index.

As in the case of output, the five categories of inputs were aggregated to form a multilateral input index using the translog multilateral index procedure proposed by Caves, Christensen and Diewert (1982)⁴. Price per unit of input was then calculated by dividing the total input cost by the aggregate input index. Note that total input cost here includes costs of labour, fuel, materials, flight equipment, and ground property and equipment (GPE).

Airline profit is calculated by dividing total revenue by total input cost. This measure reflects economic profit rather than operating profit, since the costs of aircraft and GPE are included in the total input cost.

PROFITABILITY, PRODUCTIVITY AND PRICE RECOVERY PATTERNS

This section examines the changes in airlines' profitability in relation to productivity change ratio and price recovery ratio.

North American Carriers

Exhibits 2-9 present the APC ratios for the eight North American carriers. Between 1986 and 1995, Northwest (NW), United Airlines (UA), Air Canada (AC), American Airlines (AA), Delta, and Canadian Airlines International (CAI) increased profitability by 12%, 11%, 8%, 5.5%, and 2%, respectively. In contrast, US Air experienced about 6% decline in its profitability. There were some fluctuations in Continental's profitability performance during the sample period, but not significant.

Most North American carriers improved their productivity during the period, with Delta achieving the highest productivity growth at 34%, followed closely by CAI at 29.8%. On the other hand, the carriers' price recovery ratios generally declined during the period, with the exception of Continental. Delta and CAI experienced substantial decline in their price recovery ratios, both at 21%. Profitability improvement from productivity growth was off-set by the negative impact of falling price recovery ratio. As a result, only modest profitability improvement was observed at Delta and CAI during the period. Northwest, United and Air Canada also achieved considerable productivity growth, 21%, 25% and 19%, respectively, but experienced less decline in price recovery ratio (7%, 11% and 9%,

respectively). As a result, they were able to achieve higher profitability improvement, 12%, 11% and 8%, respectively. American Airlines improved productivity growth by 12%, and endured 7% decline in its price recovery ratio. The net result was a 4.7% increase in profitability. Continental is the only North American carrier which experienced a negative productivity growth (7%) during the sample period. It is also the only North American carrier which improved its price recovery ratio (7%). As a result, there was little change in Continental's profitability between 1986 and 1995. US Air achieved a 16% improvement in productivity, but suffered a 20% loss in its price recovery ratio. Consequently, it experienced a 6% decline in its profitability. It is the only North American carrier which experienced falling profitability during the sample period.

Overall, the improvement in productivity growth was due to enhanced efficiency and changes in airlines' network characteristics (Oum and Yu, 1995). For example, average stage length of the carriers generally increased during the sample period (Oum and Yu, 1997), leading to higher observed productivity level. The declining price recovery ability could be attributed to the fact that input prices have been rising faster than airline yield (in nominal term) in North America⁵. Continental was the only carrier in North America which saw its yield rose faster than its input prices, thus improvement in its price recovery ratio.

European Carriers

Exhibits 10-16 present the APC ratios for the seven European carriers. Among the European carriers, KLM and BA made the most significant profitability improvement during the period, 15% and 14%, respectively. Their profitability improvement was achieved through significant productivity improvement of 43% and 36%, respectively, despite the considerable loss of their price recovery ratio (20% and 17%, respectively). The declining price recovery ability was caused mostly by input prices rising substantially faster than airline yields. Swissair and Lufthansa also suffered 17% decline in price recovery ratio, same as BA. Their productivity improvement (28% and 24%, respectively), however, was not as significant as BA's. Consequently, Swissair and Lufthansa were not able to achieve as much profitability improvement as BA. SAS and Iberia increased their profitability by 8% and 9%, respectively. This was a result of productivity growth of respective 13% and 16%, and a decrease in price recovery ratio of 8% and 9%, respectively. Air France appears to have made substantial improvement in productivity, but it also experienced significant decline in its price recovery ratio. The result was a mere 2.5% increase in its profitability. While most European carriers suffered loss in

price recovery ability because of yield increases not being able to keep up with increases in input prices, Air France's average yield actually declined in nominal term between 1986 and 1995.

Asian Carriers

Exhibits 17-23 presents the APC ratios for the Asian carriers. Qantas made the most significant profitability improvement at 23%. This is a result of 32% productivity growth and 7% decline in price recovery ratio, which was due mostly to the fact that input prices were rising faster than average yields. Singapore Airlines and Thai Airways also improved profitability considerably. Again, this is attributable to high productivity growth, 20% and 48% respectively, after compensating for losses in price recovery ratio, 9% and 23%, respectively. Korean Air achieved the most significant productivity growth during the period at 53%. However, it also suffered the largest decline in price recovery ratio (34%), which was a result of 65% increase in input prices overpowering the 10% increase in average yields. Consequently, Korean Air was not able to make any significant profitability improvement. Japan Airlines (JAL) was able to make modest profitability improvement (4%) despite a modest productivity growth (7%), because it was able to maintain its price recovery ratio during the period.

All Nippon Airways (ANA) and Cathay Pacific suffered considerable losses in profitability despite productivity growth of 9% and 14%, respectively. Again, this was caused by input prices rising faster than yields. This was particularly true in the case of Cathay Pacific: 50% increase in input prices versus 13% increase in average yields.

Comparison among North American, European and Asian Carriers

To compare across carriers in different continents, average change ratios for North American, European and Asian carriers are reported in Exhibits 24, 25 and 26, respectively. North American carriers, on average, saw their profitability improved between 1986 and 1988 despite a slight decline in productivity. This was a result of improved price recovery ratio. Since 1988, however, North American carriers' price recovery ratio has been consistently declining. On the other hand, productivity change ratio rose monotonically from 1991 to 1995. The combined effects of lower productivity ratio and lower price recovery ratio led to lower profitability during 1990-1992. Between 1992 to 1995, the positive impact of productivity improvement was able to over-power the negative impact of falling price recovery ratio, resulting in profitability improvement for the carriers.

European carriers also experienced improved profitability between

1986 and 1988. However, this improvement was a result of improved productivity despite of a slight fall in price recovery ratio. In general, European carriers consistently achieved significant productivity growth during the period, except for a slight stumble during the 1990-1991 recession. At the same time, their price recovery ratio dropped substantially. Profitability was at the lowest point in 1990, remained essentially unchanged between 1990 and 1993, then improved noticeably thereafter.

Asian carriers followed a similar changing pattern to that of European carriers. They achieved significant profitability improvement between 1986 and 1988, higher than their North American and European counterparts. Like the European carriers, this was mostly attributed to productivity growth. Asian carriers also consistently improved their productivity during the period, while suffering significant fall in their price recovery ability. Profitability peaked in 1988, then dropped considerably between 1988 and 1990, and had generally improved since 1990.

SUMMARY AND CONCLUDING REMARKS

This paper examines changes in the profitability, productivity and price recovery of the world's 22 major airlines over a ten year period. The increased competition in the international air transport markets have put pressures on carriers' ability to raise prices. However, input prices have been increasing continuously, especially in traditionally low-cost countries. Consequently, the overall results show that airlines have experienced continuing significant drops in their price recovery ratios during the ten-year period. To counter-act such trends, airlines have made tremendous efforts to improve efficiency, as borne out by the steady increasing trend in productivity change ratio during the period. As a result, overall profitability of the airlines have improved in the 1990s.

The results further show that European carriers and Asian carriers consistently improved productivity throughout the period even during the time of rising profitability. This is particularly true for European carriers. The liberalization measures undertaken in Europe via package #2 (1990) and #3 (1993) appear to have made significant impact on carriers' performance. As a result, European carriers have achieved higher productivity growth than Asian and North American carriers. North American carriers, on the other hand, experienced a rather "flat" period in productivity growth between 1986 and 1991, then started to exhibit significant productivity improvement after incurring losses in profitability during the recessions. This "flat" period may be explained by the fact that the US carriers achieved tremendous productivity growth immediately

following the US domestic deregulation in 1978, then entered a "plateau" period in the late 1980s.

European carriers and Asian carriers experienced considerable losses in price recovery ratio, much more than North American carriers. This is because their input prices have increased rapidly, while air fares have declined due to increased competition.

Although overall impacts have been positive, the study shows that different dynamics at work at the firm level. Some carriers seem to have had difficulty adjusting to the deregulated environment and improving their profitability and productivity in a sustained manner, while others are consistent in the patterns of improvement of the various components of their performance. It is important for carriers to achieve high efficiency and productivity, thus lower cost. It is also important for carriers to price intelligently and properly manage yields in order to maintain and enhance their price recovery ability.

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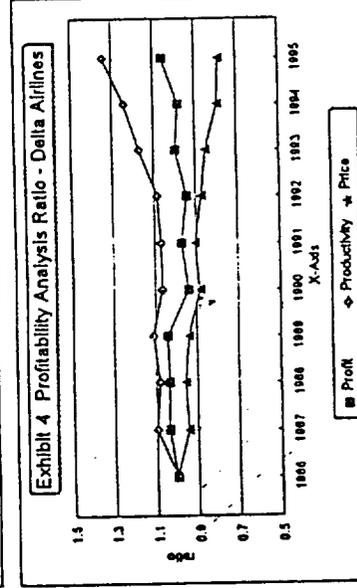
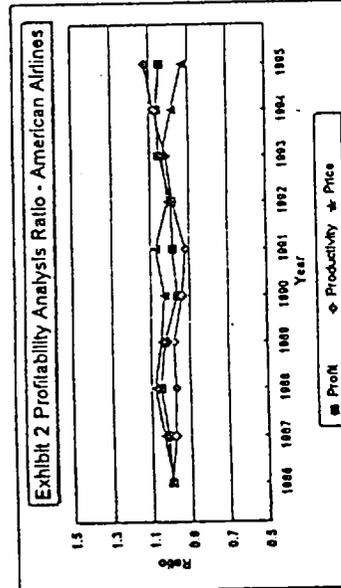
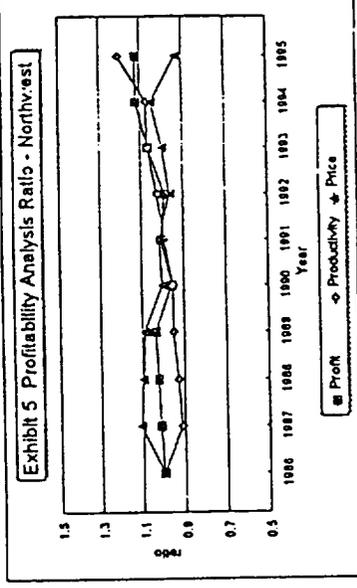
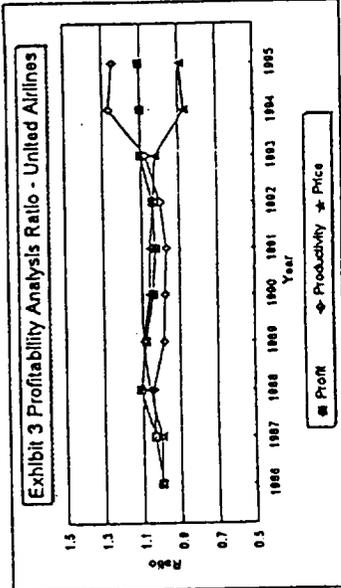
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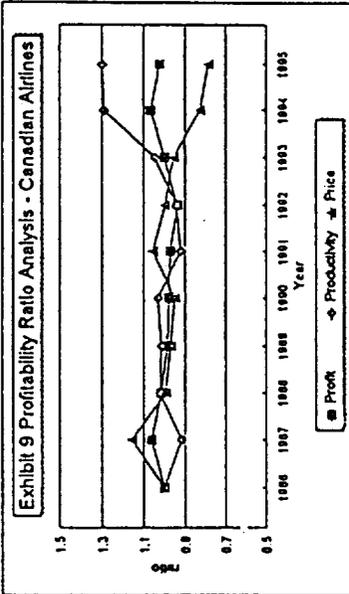
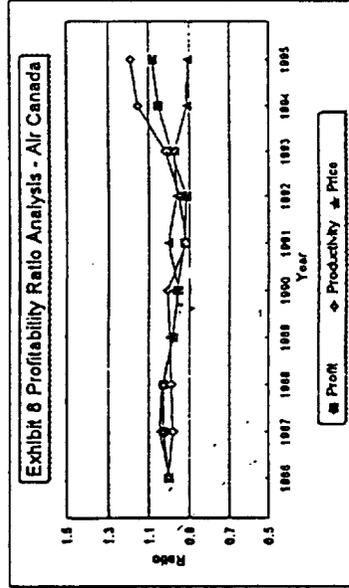
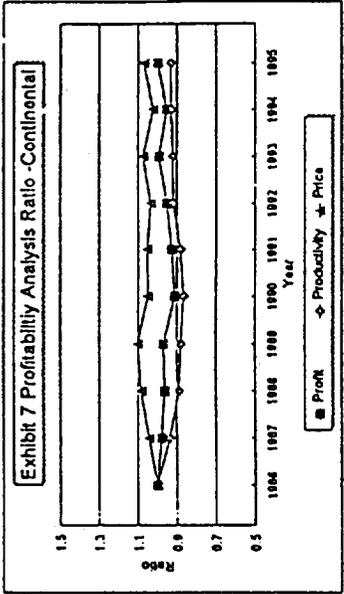
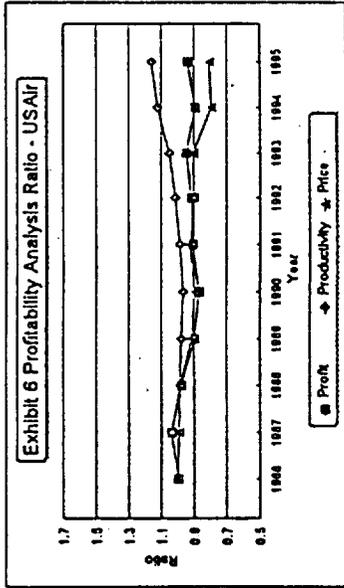
1. More discussions on the airlines can be found in Oum and Yu (1995).
2. CAI earned a modest C\$5.4 million profit in 1997, its first since 1988 (Daniels, 1998).
3. The aircraft leasing price data were kindly supplied to us by Avmark, Inc..
4. Revenue shares (cost shares) are used as the weights in aggregating outputs (inputs). As a result, higher weights are given to outputs with higher yields. Similarly, more expensive input factors are given higher weights in aggregating inputs.
5. Note that airline fares in real terms have been consistently declining over the last three decades (Boeing, 1997).

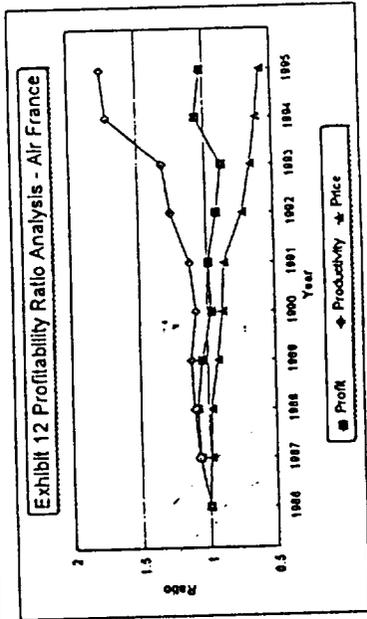
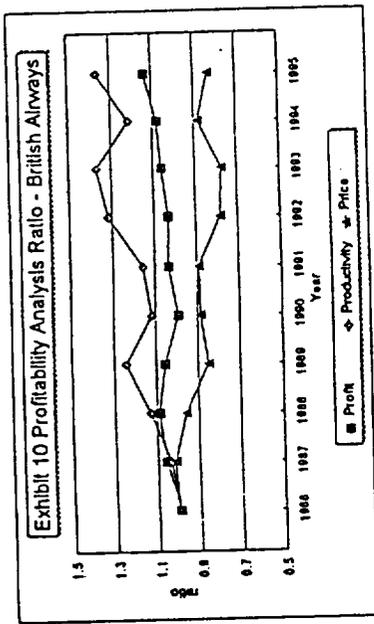
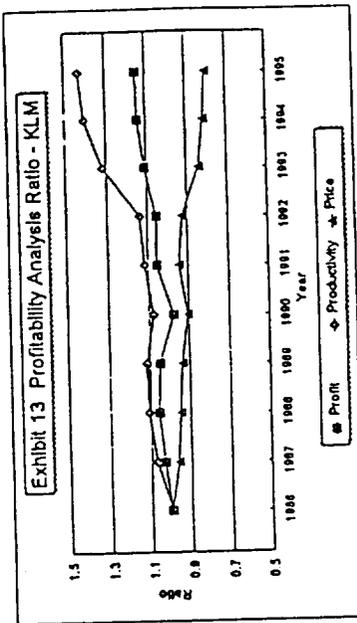
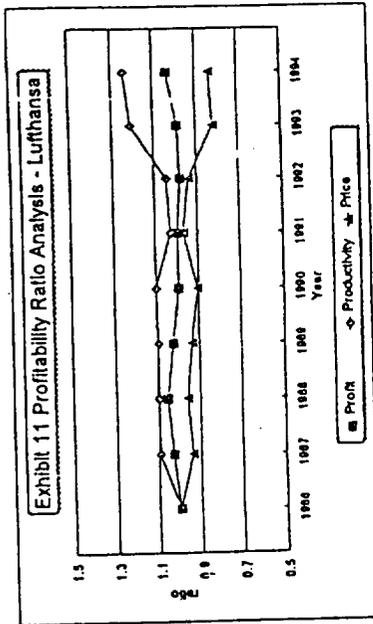
Exhibit 1 Descriptive Statistics of Sample Airlines, 1995

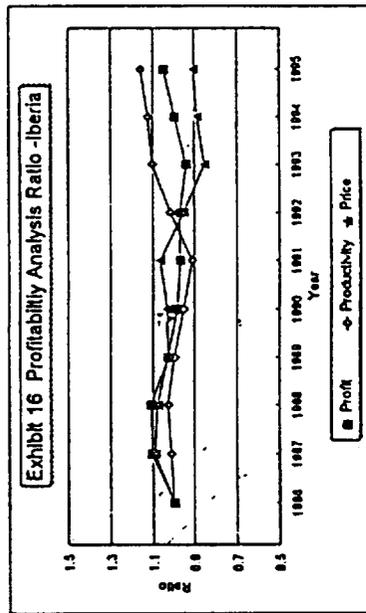
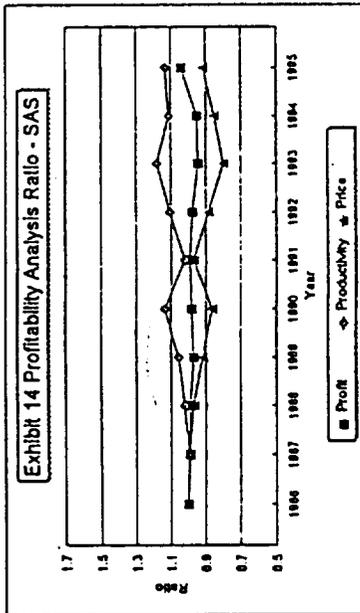
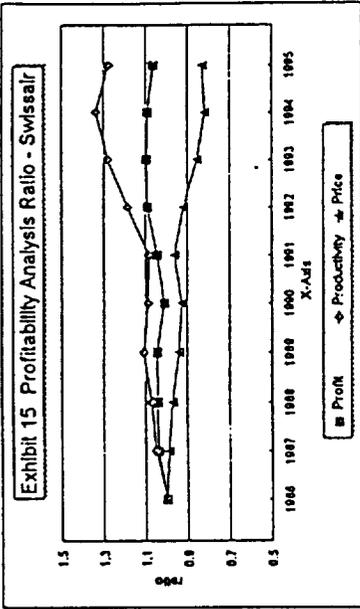
Airline	Total Revenue (Million US \$)	Revenue Tonne-km (millions)	Number of Passenger (thousands)	Number of Employees (units)	% Int'l RTK	Stage Length (km)	Passenger Load Factor (%)	Weight Load Factor (%)	Rev/Exp Ratio (%)
American	15,610	17,660 ^a	79,389 ^a	90,980	36.9	1,799	69 ^a	52	106.6
United	14,895	19,637 ^a	81,945 ^a	80,902	42.3	1,683	72 ^a	59	105.9
Delta	12,557	15,168 ^a	97,271 ^a	62,832	30.7	1,224	70 ^a	55	109.0
Northwest	8,908	12,821 ^a	52,722 ^a	44,192	47.8	1,362	73 ^a	60	111.4
US Air	6,985	5,949 ^a	56,893 ^a	43,614	7.4	904	69 ^a	52	103.5
Continental	4,919	6,099 ^a	33,986 ^a	32,272	20.0	1,215	68 ^a	61	105.1
Air Canada	2,332	3,453	12,801	20,503	67.3	1,536	63	53	106.9
Canadian	1,938	2,948	8,378 ^a	13,228 ^a	70.1	1,681	71 ^a	68 ^a	98.6
Japan Airlines	10,884	10,204	28,880	20,482	85.6	2,348	68	66	101.5
All Nippon	8,737	4,583	37,870	14,649	41.2	1,112	64	51	103.3
Singapore	4,440	9,512 ^a	12,022 ^a	13,258	100.0	4,300	74 ^a	71	113.3
Korean Air	4,362	8,261	21,422	16,478	93.9	1,714	65	56	108.7
Cathay	3,696	7,092 ^a	10,983 ^a	15,657 ^a	100.0	3,383	74 ^a	71	118.4
Qantas	3,063	6,603 ^a	15,531 ^a	24,429 ^a	79.5	2,064	72 ^a	64 ^a	106.6
Thair	2,926	3,795	12,821	20,718	92.0	1,559	67	69	114.7
British Airways	10,716	12,215	33,000 ^a	50,477	98.1	1,863	72 ^a	71	116.6
Lufthansa ¹	9,231	12,205	32,999	26,578	95.2	1,131	70	71	100.8
Air France	6,510	9,701	14,498	36,384	91.1	1,846	71	71	103.2
KLM	5,547	8,630 ^a	12,285	26,385 ^a	99.9	1,748	76 ^a	73 ^a	105.1
SAS	4,597	2,195	19,828 ^a	21,348 ^a	83.1	728	64 ^a	61	108.4
Swireair	3,483	3,574	8,826 ^a	16,570	99.0	2,268	64	69	101.2
Iberia	2,902	2,850	14,600 ^a	22,500	79.6	1,194	70	61	107.5

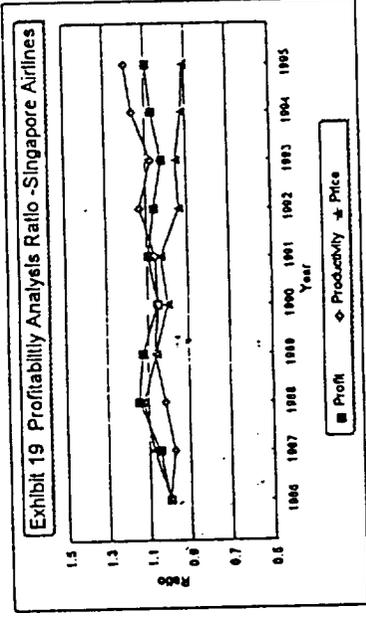
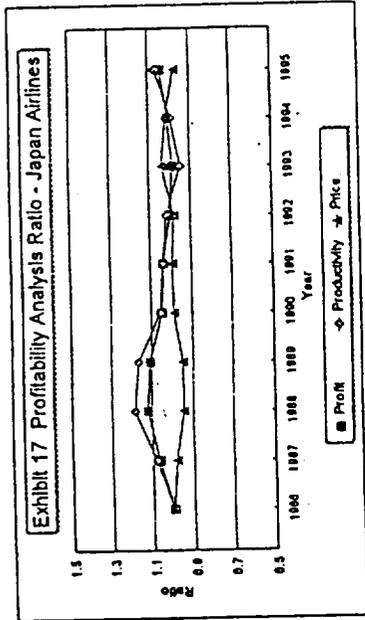
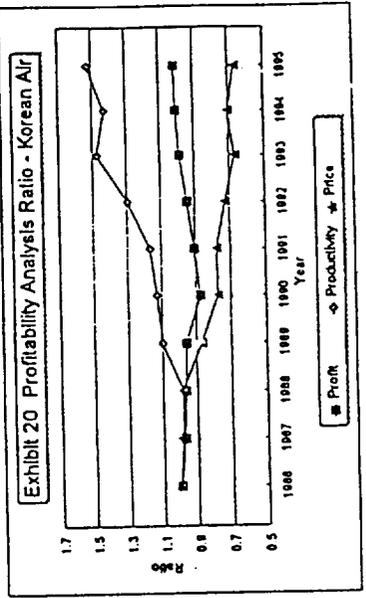
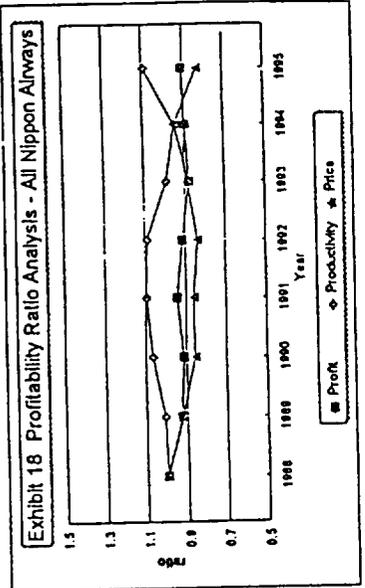
^a 1996 data; ¹ Lufthansa was through dramatic restructuring during 1994-1995. Its Technical Services and Cargo divisions became independent public limited companies on January 1, 1995. The parent company Lufthansa AG is now purely a scheduled passenger airline company.

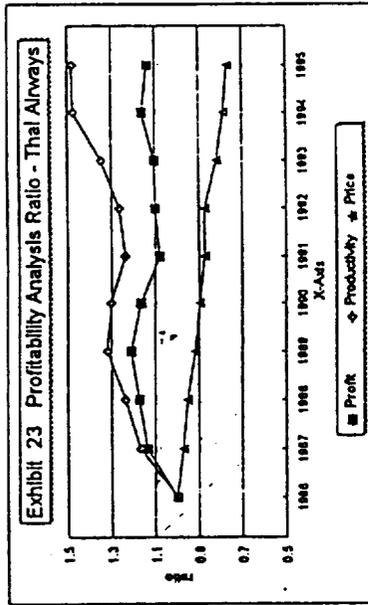
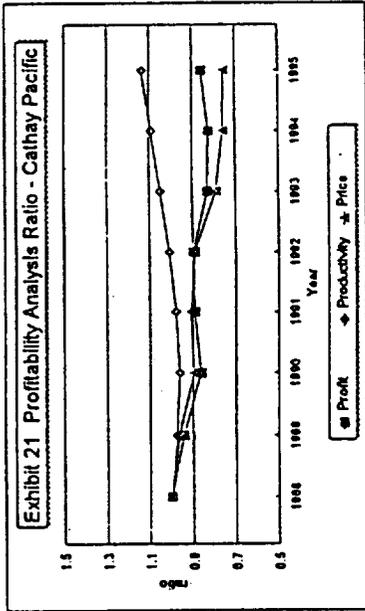
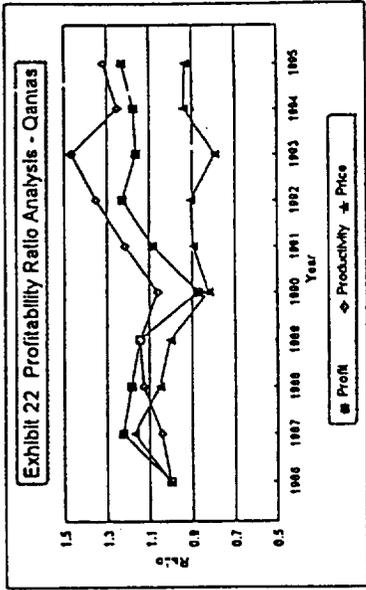


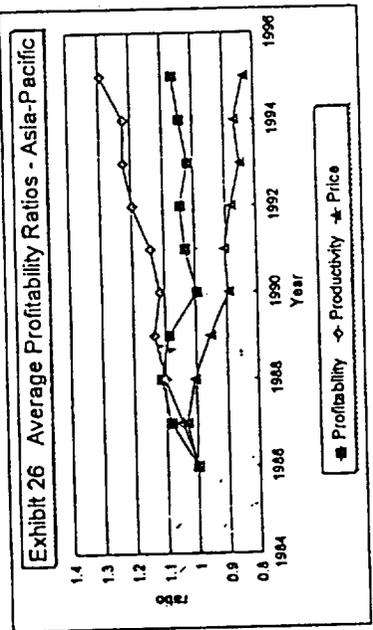
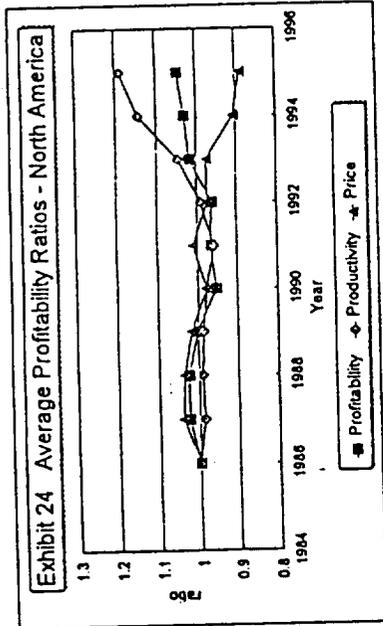
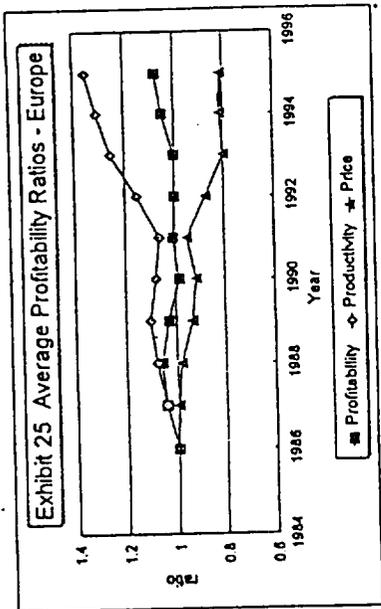














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**Airlines, Governments, and the Distribution of Air Travel
Services in a Changing Global Economy**

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1 GLOBALIZATION IN THE AIR TRANSPORT INDUSTRY

Much is being made of the growing trend towards globalization of the air transport industry. Airline officials, economists, policy makers, and others publicly trumpet the virtues of an air transport industry with fewer trade barriers, less government intervention, increased levels of privatization, and more efficient airlines (Kaspar 1988; Gialloreto 1988; and OECD 1993 and 1997). For these observers, globalization is not only a reality, but a welcome sign of progress in an industry that has been characterized historically as highly regulated and influenced by politics, instead of market forces. This paper examines the trend towards globalization in the air transport industry with special focus on the behavior of governments and firms, namely airlines, and the tactics or strategies employed by these groups in their efforts to shape the industry to meet their preferred outcomes. The central issue in this study is whether the liberalization or regulatory reform that emerges from the interaction of governments and airlines actually produces a globalized industry that is better situated to serve the air transport needs of the global community, or a restructured industry that is better situated to serve the interests of the dominant airlines and the industrialized economies from which they operate.

This paper is distilled from a more comprehensive project on the implications of globalization and liberalization in air transport. It is organized to give the reader with some background in the political economy of the air transport industry, but perhaps a limited knowledge of the concept of globalization, a sufficient foundation of knowledge to make sense of the analysis and arguments about the current trends and probable future of the industry. Thus, after an initial discussion of the concept of globalization, the second section of the paper briefly outlines the history of the international air transport industry. The third section discusses the American roots of current international liberalization efforts and the particular role that American airlines play in the political and economic transformation of this industry. This discussion is followed by an update of the industry, which is changing quickly and, in some cases, quite dramatically. The final two sections offer some analysis and conclusions about the ramifications of the current trends in liberalization of the air transport industry with special attention on the impact of these trends on policy making and economic growth and development in both the industrialized and developing worlds. Two cases, one focusing narrowly on St. Louis, an American city, and the other focusing broadly on Africa, help bring the theoretical and abstract discussion into the real world of policy making and commerce.

1.1 Globalization: What is it and is it really global?

There is considerable literature on the phenomenon known commonly as globalization. This literature is characterized generally by its inability to carefully define what is meant by the term "globalization." In international relations theory, the literature splits along familiar lines when discussing the concept, with liberal theorists seeing globalization as a function of increasing, and for the most part welcomed, interdependence; and realists seeing globalization as ephemeral or inconsequential.

For liberal scholars, globalization is part of the evolution of the international system to a new plane of cooperation and peace that is facilitated by increasing levels of communication and interaction. Not surprisingly, air transport is included among the various technological means by which the global community is able to come together to exchange not only goods and service, but also ideas and mutual interests. Moreover, the globalization of air transport has special significance for liberal theorists who contend that

an efficient global air transport system facilitates economic exchanges that will help foster further integration of developing world economies into the more successful economic system of the industrialized world (Jonsson 1981). These scholars join together with increasingly influential community of scholars and policy makers who firmly believe that liberalization of trade in goods and services will serve the needs of the global community in ways that the state-centered policies of the past were incapable (Button 1991).

Realists and skeptics of the positive impact of globalization continue to stress the abiding relevance of the nation-state and power relationships between nation-states in the international system. For realists, the transformation of the air transport industry is not troubling, since much of what has happened, such as the increasing number of “open skies” agreements, can be explained as a function of power politics, in which the United States has been able to forcefully represent the interests of its own airlines (Nayar 1995). This explanation is not completely satisfying, as will be shown later in this paper, but there is some merit to the claim that nation-states, particularly the economically and political powerful have attempted with some success to shape liberalization and globalization to fit their needs and interests.

A more intriguing position on the issue of globalization, and the one that is presented in this paper, is that despite realist claims, the nation-state is losing its grasp on the political economy of the air transport industry. This argument has its foundation in the way in which airlines, especially American carriers, seized on new technologies and strategies that allow them to pursue their competitive advantage in the air transport industry. It is these technologies and strategies that fundamentally changed the way in which international air travel is conducted, and dramatically changed the relationship between governments and airlines in the development and implementation of national airline regulations and policies. The transformation, which is discussed in detail later, initiated a trend towards liberalization of the global air transport industry. This liberalization has become synonymous in the minds of many industry observers, policy makers, and scholars with globalization. The widely accepted conclusion is that current liberalization efforts will effectively globalize the industry and the global economy will reap the benefits of a more efficient air transport system. This study questions the theoretical and empirical basis for this conclusion and argues instead that the character of current liberalization efforts will lead to a mix of positive and negative economic and political outcomes. The primary argument is that the globalization of the air transport industry is not really global and will create problems that are not easily solved.

2 HISTORY OF AIR TRANSPORT REGULATORY REGIMES

It is impossible to understand the current trends and issues in the air transport industry without some background in the foundations of aviation regulation. While, early discussions about sovereignty of the air can be traced to Europe prior to the development of practical aircraft, most scholars begin their coverage of aviation regulation with the Chicago Conference of 1944. The Chicago Conference established four basic principles that have been more or less upheld since 1944, but have come under implicit challenge from current liberalization and globalization efforts. These principles are:

- *Sovereignty* -- each state has complete and exclusive sovereignty over the air space above its territory.

- *Equal opportunities* -- all states are given equal rights to participate in aviation regulated through international agreement.
- *Non-discrimination* -- international aviation regulations must not discriminate on the basis of nationality.
- *Freedom to designate* -- each state has right and freedom to designate its national carrier.

2.1 ICAO and multilateral cooperation

These principles were embodied in a newly created international institution - the International Civil Aviation Organization (ICAO). ICAO has been held out as evidence of multilateral cooperation in the management of international air transport, but this claim is less compelling when placed in the broader context of aviation regulation. Despite the efforts of some nations to develop and implement a multinational air transport services agreement at the Chicago Conference, there was sufficient reluctance on the part of others so as to leave the negotiations of air traffic rights to individual pairs or dyads of states. The result was an aviation system regulated by a series of bilateral agreements in which two sovereign nations decide between themselves the nature of the traffic rights and standards of operation between and within their airspace. Not surprisingly, there are over 1,200 such bilateral air service agreements (Abeyratne 1996, World Tourism Organization 1994).

2.2 Power politics and bilateral air service agreements

The bilateral agreements typically spell out the nature of the relationship between the governments and airlines of the two nations. Specifically, the bilaterals stipulate which of the various "freedoms" will be included in the bilateral. In other words, the bilateral codifies standards, tariffs, schedules, landing rights, capacity levels, safety regulations, exemptions, and other operational issues. The model for most bilateral agreements is the so-called Bermuda Agreement, signed by the United States and the United Kingdom in 1946 and renegotiated as Bermuda II in 1977 (Sochor 1991).

The bilateral regime, as it is often called, is held up as evidence for the abiding relevance of power politics in the air transport industry (Nayar 1995). According to realists and critics of the regime, bilateral agreements tend to favor the most powerful state in the dyad, effectively creating a asymmetrical distribution of benefits from the trade in air services between the two countries. Realists, as theorists of international relations, are not unhappy with this conclusion since it seems to confirm their hypotheses about primacy of national power. The claims of the critics of the regime are much more interesting in general and are especially relevant for this study. These critics argue that the bilateral framework is an anachronism in an age in which other sectors of the international economy are liberalizing at break neck speed and doing so primarily through multilateral agreements and institutions. Bilaterals, they say, are preventing the globalization of an efficient air transport system that could increase and expand global economic development (Feldman 1994; Oum *et al* 1993; and Hufbauer and Findlay 1996).

3 REGULATORY REFORM IN THE U.S. AND THE PUSH FOR OPEN SKIES

Not surprisingly, much of this criticism comes from governments and airlines that would rather operate under a renegotiated bilateral system or a more liberal, open skies arrangement. Momentum towards open skies began nearly two decades ago, shortly after domestic regulatory reform in the US in 1978. The US government publicly committed

itself to an international open skies regime in which the international air transport industry would undergo regulatory reform much like the domestic reform undertaken in the US. The international liberalization effort got off to a slow start, in part because the US domestic air travel industry began a tumultuous period of competition, acquisitions, bankruptcies, and consolidation which ran through the 1980s and has only recently showed signs of calming. By 1990, however, it became clear to US airlines and the government agencies that regulate them, that American carriers were ready to take on the rest of the world and forge ahead with political efforts to open the skies (USDOT 1994).

Several major airlines in the United States, especially the so-called Big Three (Delta, United, and American) survived the fierce competition of domestic regulatory reform and liberalization to emerge as efficient, competitive carriers ready to do battle with foreign airlines. An important edge held by the American carriers was their extensive networks in the lucrative US domestic air travel market. One of the other important ramifications of domestic regulatory reform was the emergence of the hub and spoke system within the US market. The air travel market is now characterized by hub airports and spoke or feeder airports (Doganis 1991).

3.1 The emergence of the hub and spoke system

The basic structure of the hub and spoke system is quite simple and it reflects airlines' efforts to consolidate operations and do business more efficiently. An airline, such as Trans World Airlines (TWA) which operates a major hub out of St. Louis, Missouri, will funnel its passengers through its hub instead of offering point-to-point non-stop service between numerous city-pairs. A passenger who wants to fly TWA from Seattle, Washington to Atlanta, Georgia would have to change planes in St. Louis where she will join other passengers from around the country who fly into St. Louis before boarding another TWA flight to their final destination. The practical effect for passengers is that hubs limit choices, increase travel times, and increase chances of transfer delays and mishandled baggage. The practical effect for the airlines is mixed. The hub carrier benefits from having considerable control over originating traffic at their hubs (70-75% is not uncommon for so-called fortress hubs) and a cost-effective means for managing operations. Non-hub carriers or carriers operating out of someone else's hub suffer because the strength of the hub carriers at their respective hub airports (Doganis 1991 and GRA, Inc. 1994).

While the hub and spoke system has had considerable impact on the structure of the American airline industry and the American airport system, it also has implications for the liberalization of the international air travel market. For some observers, the hub system conveys even further advantages on already strong American carriers, such that the gains from more liberal skies will be illusory for those foreign carriers that might operate under the more open regime. This issue is taken up in more detail later in the paper.

3.2 The International Airline Competition Act

The US government, acting on behalf of its airlines, passed legislation in 1979 that called for the liberalization of the global air transport market. Not surprisingly, policy makers and American carriers believed they could compete effectively against the foreign airlines. As noted earlier, this initiative got off to a very slow start, in part because the US airlines were busy trying to kill each other off in fare wars, acquisitions, and other commercial battles for supremacy of the lucrative US market. In a rather odd turn of events, the

carriers that primarily represented the US in the international market, Pan Am and TWA, took severe beatings because they lacked crucial feeder networks within the US domestic market. The Big Three, relying on their substantial domestic networks turned an eager eye to the international market, and asked the government to do something to help.

There is not enough space here to detail all the bargaining, negotiations, and rhetoric associated with the US government's efforts to cajole, pressure, or leverage the skies open to American carriers, but one point is important for this study. The airlines were at a minimum impatient and unhappy with the lack of progress being made in opening the skies, and more likely, worried about their relative positions in the global air transport market once it was eventually liberalized. The thinking among airline executives was not *if*, but *when* the market would be open, and more importantly, would they be ready to compete (Gialloreto 1988; and Oum *et al* 1993) This lack of patience and the competitive urge to gain advantage led to a number of important innovations in the way airlines do business in the international market. These innovations dramatically reshaped the character of the airline business and what a liberalized or open air transport market would actually look like.

4 NEW STRATEGIES AND TECHNOLOGIES

When governments in North America, Europe, and Asia began to talk about "open skies" or some other liberalization or restructuring of the bilaterals that governed air services between their various countries, the airlines watched carefully and in most cases actively lobbied for their various interests to be preserved. As one might imagine though, the interest of one US airline may not be the same as the interests of all US airlines. The introduction of new technologies and commercial strategies exacerbated these potential differences and created new problems for airline competition and government policy makers and negotiators.

Among the most intriguing applications of new technology to the airline business is the development and expanded use of computer reservation systems (CRS). On its face, CRS seems like just another computer-based information or management tool by which an airline can better manage its sales of tickets, its marketing, and its service to its customers. Upon more critical inspection though, and taking into account the way that CRS has been used in the airline industry, this technology plays a tremendous role in the way business is done, the way in which airlines compete, and the way a liberalized market might work. It is therefore, important to understand how CRS and strategies that develop from its application have restructured the relationship between governments and airlines and transformed the market itself.

4.1 Computer Reservation Systems (CRS)

CRS technology allowed airlines to apply computer-based management and marketing tools to their operations, with the intention of making the process of reserving seats, processing tickets, and tracking consumer demand more efficiently. Frequent air travelers might wonder at this point whether CRS really makes a difference since it seems that air travel still involves an endless hassle of exchanging pieces of paper, confirmation numbers, and phone calls in order to make a single flight. CRS has made a difference though in that the booking of flights and itinerary information is much better managed whether the consumer uses a travel agent or books his own flight. But this is not really the important issue when one considers the impact of CRS on the air transport industry.

The technological impact of CRS is only understood when one considers the broader application of the technology in the form of new strategies, namely code-sharing and yield management. Neither of these commercial strategies would be possible without CRS. Moreover, the application of CRS technology in code-sharing and yield management changes the character of competition in the airline industry in ways that are not yet completely understood. The nature of liberalization or globalization of the industry cannot be understood then unless CRS, code-sharing, and yield management are examined alongside other trends and issues that are shaping the evolution of modern air transport (Leaming 1993; Shenton 1994; GRA Inc. 1994).

4.2 Code sharing

Each airline in the world is assigned a two-character code that is used to designate that carrier in all aspects of official airline business. For the purposes of reservations systems, the code serves as the identification of an airline on a travel agent's computer screen. Thus, a travel agent will read the two-character code and the flight number to determine which airline and which flight is being booked. While seemingly mundane, this is an important issue in any analysis of the air transport market, because of the development and application of code-sharing.

Code-sharing is an agreement by two carriers to list flights under one carrier's code so that a passenger does not know that she is actually booking the various legs of her flight on two separate airlines. From the airlines perspective, this process is designed to serve the consumer better, since "seamless" travel is available to more destinations. Consider, for example, a passenger who wants to fly from Carbondale, Illinois to London, England. Obviously there are no direct flights from Carbondale to London, so the passenger realizes that connecting flights will be necessary. Two possibilities emerge that illustrate the code-sharing issue.

- In the first possible itinerary, the passenger calls a travel agent and books a flight from Marion, the local airport, to St. Louis to connect with a TWA flight direct to Gatwick Airport, which serves London. Although the Marion - St. Louis portion of the trip will be made on a propeller-driven aircraft operated by a commuter airline, code-sharing shows the trip as seamless travel on TWA.
- In the second possibility, the passenger decides she doesn't want to fly TWA across the Atlantic so she asks her travel agent to determine which other American carriers offer service to London. Her travel agent says she can get a USAirways flight from St. Louis to Heathrow with a stop in Pittsburgh. Because of the code-sharing arrangement between USAirways and British Airways (BA), the leg of the flight from Pittsburgh to London will actually be on BA.

None of this might matter to the passenger, if she is simply concerned about the cheapest fares or convenient times. It would matter, however, if she doesn't want to fly on commuter aircraft or does not want to fly a foreign carrier. From the consumer's perspective, the lack of transparency in the CRS can amount to false advertising.

Why then do airlines and governments seem to find code-sharing so attractive? Code-sharing is attractive to airlines because it allows them to expand, in some cases

dramatically, the destinations that they can market as part of their route network. Moreover, the airlines who conclude code-sharing agreements with airlines which serve markets which they cannot serve themselves because of economic or political reasons, effectively avoid the expense or the regulations that constrain their operations.

It should come as no surprise then that code-sharing has been used aggressively by carriers who want to gain access to new markets, but cannot afford to do so or are prohibited by various governmental or capacity restrictions. Code-sharing between US carriers and European carriers illustrate the attractiveness of this strategy for solving a variety of difficulties. In the case of Northwest Airlines and USAir, both airlines suffered during the fierce competition after domestic regulatory reform and teetered on the edge of collapse. In both cases, the airlines were saved by cash-infusions coming from KLM and British Airways, respectively (Tarry 1996). A significant part of each deal was the conclusion of code-sharing agreements that would give the European carriers substantial access to the US domestic market without having to jump seemingly insurmountable political and economic hurdles that limited their access. At the same time, the US airlines were able to stave off collapse and market service to new foreign destinations which were actually part of KLM and BA's existing route structure.

The political importance of these and other code-sharing arrangements is that airlines, whether explicitly or implicitly, were able to circumvent the governmental process which was meeting only limited success in opening the skies between Europe, North America, and Asia. With CRS and code-sharing, airlines were able to do what government negotiators were not. Code-sharing developed quickly into strategic alliances or marketing alliances in which as many as five airlines around the world jointly market and coordinate their flights (Shenton 1994, Leaming 1993). Airline executives realized that code-sharing and alliance strategies were not only critical while they waited for governments to sort out the political problems associated with opening the skies, but would be especially important in determining who would dominate the skies once opened. In that vein, American Airlines and British Airways have proposed a code-sharing alliance which would join the two dominant carriers' route networks together to create a global giant (Morrocco 1996). Ironically, American was among the most vociferous opponents of the KLM and BA deals with Northwest and USAirways.

4.3 Yield management

A more recent technique in the airline industry is also an off-shoot of the computer reservation systems technology. Airline managers recognized that the information available to them through CRS would not only help them market their product better, but could also allow them to squeeze profits in ways that were previously unimaginable. Yield management refers simply to the computer-based software that allows airlines to market each seat on each aircraft in ways that reap the highest profit. Instead of offering simple fares for each class, airlines can now tailor fares and discounts to increase the probability that planes will take-off with as many seats filled as possible. Fares are constantly adjusted to account for changing demand and more importantly the willingness of the flying public to pay certain fares. With aggressive yield management, it is possible that the person sitting next to you paid over three times the amount you paid. Conversely, so you don't become too excited, you might have paid three times as much as she did. Most passengers understand that fares vary according to advanced purchase criteria, but most don't consider the disparity in actual fares (Saporito 1995)

Code-sharing, strategic alliances, and yield management techniques are mentioned here because they have and will continue to shape the competitive environment in the air transport industry. A better understanding of the extent to which these technologies and strategies are used to thwart competition is critical to any analysis or forecast of the global air travel market. In a recent statement by the US Department of Transportation (DOT), these issues were raised as potentially anti-competitive (Transcript 1997). The DOT noted that CRS can be used to effectively exclude smaller and lower-cost carriers from the choices readily available to the consumer. Larger carriers own CRS and structure them in ways that are not entirely transparent or fair according to the DOT. The DOT went on to say that yield management techniques are raising serious questions about predatory pricing.

The inherent flexibility and dynamic pricing that make yield management techniques attractive to the airlines also make them effective tools for rapid adjustment to low-cost competition. It is a difficult question whether this use of the technology is anti-competitive or merely an appropriate application of business tools that allow for more efficient operation. Consumer groups argue the former, claiming that airlines who use yield management do not do so transparently. They point to airline objections over publication of average fare information as evidence that the airlines are trying to hide something. The DOT expresses similar concern in that fares which decline to meet or beat new low-cost carriers, almost always go back up when the competition has been eliminated. Again, the question of whether this is fair or not is difficult, but to the extent that the larger carriers are more likely not to be able to afford and manage yield management systems, it seems that low-cost entrants are at a disadvantage.

The successful application of these technologies in the North American and European markets raises important questions about the nature of a more liberal international air transport market. In both the United States and the European Union it seems that the technological and strategic innovations employed by the successful airlines have outstripped both the regulatory and policy making communities in those polities. The US Department of Transportation and the US Department of Justice seemingly made early decisions on code-sharing and strategic alliances with insufficient data and analysis about the impact of such arrangements. Similarly, the EU is grappling with the implications of the proposed alliance between American Airlines and British Airways. To be fair, the difficulty of making policies on-the-fly should not be underestimated. The industry is changing quickly and policy makers have the difficult task of sorting through the claims and counterclaims of the airlines themselves. How, for example, should a policy maker who listened to American Airlines rail against the British Airways bailout of USAir interpret the proposed alliance? The key perhaps is to remember that individual airlines are best thought of as representatives of their own interests. Despite their occasional claims of representing what is good for the consumer or their nation, the airlines are most interested in their own success. One cannot blame them for this, but it is something that must be remembered when we consider the effort of the dominant airlines to further liberalize the global air transport system. By keeping the events of the past several years and the interests of the dominant carriers in mind we can paint a plausible picture of the future.

5 THE FUTURE OF GLOBAL AIR TRANSPORT

The future will most likely be shaped by current trends and ideas about liberalization. As of this writing, it is fairly clear that major airlines and governmental actors in the international system are no longer talking about whether to liberalize or not, but when and how. Moreover, it seems that discussions about air transport are being shaped by trends in other industries and sectors, in which liberalization is in full-swing. In these industries the concepts of privatization, elimination of subsidies, elimination of cross-subsidization, and the implementation of standards are realities. Air transport seems to be heading in the same direction.

Liberalization of air transport has a number of components. This study examines several of these components with specific attention to their ramifications for the industry and the flying consumer. These components include reform in the areas of cabotage, foreign ownership, subsidies, cross-subsidies, and privatization.

5.1 Cabotage and foreign ownership

Among the most difficult components of a comprehensive liberalization package are foreign ownership and cabotage. It is common for nations to impose limits on foreign ownership of its airlines. The limits vary, but the general rule is that controlling interest of carriers must remain in the hands of nationals, or in the case of the EU, citizens of member states. For some, the limits on foreign ownership are relics of a bygone era in which nations were fiercely protective of their flag carriers for economic and security reasons, as well as prestige (WTO 1994; OECD 1997; Button 1991; and Feldman 1995). For others, foreign control of airlines represents a dangerous loss of sovereignty and autonomy. Similarly, cabotage is held out as a matter of national security interests, but its impact is more clearly economic.

Cabotage is the right of a foreign carrier to carry passengers on flights entirely within another country. In other words, cabotage rights would give British Airways the right to pick up passengers in New York and fly them to Dallas. A related issue is the granting of beyond rights, which would allow, for example, United Airlines the right to fly from San Francisco to Tokyo, pick up Japanese passengers and fly on to Seoul. As one can imagine, the fear of granting such rights is that foreign carriers have the opportunity to take business away from national carriers (Abeyratne 1996).

While both are included in official discussions about open skies, these issues are unlikely to be resolved soon since cabotage and foreign ownership amount to direct concessions from national airlines. Airlines, whether they are competitive or not are loath to open themselves up for more competition. Some observers believe that change on these issues will not come until the United States changes its position on limiting foreign ownership of US carriers and allowing foreign carriers cabotage rights in the lucrative US domestic market. Put simply, these issues are unlikely to be resolved in the near term, although concessions might be made by the Americans in order to secure access to other countries.

5.2 Airport capacity

Perhaps a more intractable issue in the liberalization of the global air transport market is that issue of capacity or, more simply, places to land and park airplanes. It is easy to think of the airline industry as simply the firms that fly and maintain the airplanes that ferry

people and cargo from place to place. That this happens efficiently or at all is as much a function of airport capacity as it is the successful operation of the aircraft themselves. It should come as no surprise then that airports are a critical link in the process of liberalizing the air transport market. It will make little difference to the market if the US government convinces the UK to allow more direct flights of US carriers to London if Heathrow airport cannot handle any additional landings.

The importance of this issue is evident when one examines airport capacity in the major cities around the industrialized world and realizes that most airports are at capacity. More importantly perhaps, building new airports or expanding old ones is typically not an easy economic or political task. Enormous financial, environmental, and political hurdles confront virtually every airport project (Kapur 1995; Thurston 1995). To the extent that new capacity will only slowly develop, the question shifts back to the trickier issue of reallocating landing slots and terminal space in such a way that new competition can actually compete (Hufbauer and Findlay 1996). Again, it should come as no surprise that incumbent national airlines have the upper hand in protecting their share of landing slots. Despite American complaints about Heathrow in London and similar difficulties elsewhere, one sees similar intransigence at hub airports in the United States where, as noted earlier, hub carriers can control as much as 75% of the business at a major airport.

There are a number of proposals circulating in the air transport community which suggest ways to liberalize the allocation of landing slots, but few seem to satisfy the various stakeholders involved in the management and use of the world's airports (Hufbauer and Findlay, 1996). Ironically perhaps, the airlines themselves are often opponents of airport expansion and development because they are forced to shoulder the financial burden through increased landing fees. No airline is interested in paying for the development of new capacity if it will benefit its competition. Airlines, like other businesses, would rather have someone else pay for the expansion and then let the airlines decide who gets to utilize the new capacity. Needless to say, the issue of airport capacity is among the most tricky political issues to face local and national political leaders.

5.3 Privatization

One trend that recognizes the difficulty of satisfactory public policy solutions to the air transport issue is to privatize both airlines and airports. Given the discussion of airport capacity above, it is not difficult to understand why policy makers might be willing to give up control over airports even though they represent an enormous potential for patronage contracts and jobs, as well as a certain amount of prestige. For many political leaders in the United States and Europe, the business of running an airport has lost its luster. The regulatory reform which liberalized the airline industry in these markets changed the relationship between the airport managers and their primary customers, the airlines. Airports cannot rely on business as usual in an environment in which the airlines are constantly jockeying for competitive advantage (Tarry and Fuller 1997). The fierce competition between US carriers and the liberalization of European air transport will necessarily put additional pressure on airports to play some competitive role in the market. Airports can no longer operate as public utilities, they must develop commercial strategies and keep a vigilant eye on the market, which may determine whether the airline they depend on will stay in business.

Just as many airports have new pressures and demands placed on them to operate as businesses, most airlines in the industrialized world are being cut off from their public safety net. Subsidies and government bailouts are increasingly discouraged, either formally through regulation or informally through political pressure. Governments, trade scholars, and the successful airlines have all joined the chorus calling for an end to government subsidy for unprofitable and publicly owned carriers (Button 1991; OECD 1997; USDOT 1994). Increasingly, governments are moving to divest themselves of their airlines – hoping to force the carrier to compete in the open market as a lean, efficient business, not as a bloated social service. The results are mixed and their interpretation depends in large part on where you sit. If you are an economist or an executive of a successful carrier, you are no doubt elated with the ability of the market to cull the weak from the herd. On the other hand, if you are concerned about evenness of air transport services or perhaps you had a job with one of the failed carriers, your interpretation probably ranges from caution to despair, respectively.

5.4 More on subsidies and cross-subsidies

Of the more difficult aspects of the liberalization trend to deal with politically, is the limiting or prohibition of subsidies and cross-subsidies. As noted above, it is often the case that the interpretation of the utility of liberalization in these areas depends on your position in the market. It is also important to note that the nature of the airline industry suggests that the prohibition of subsidies may have deleterious long term effects on the provision of air transport services. This problem has more to do with the structure of the air transport industry than it does with the operation of any particular airport or airline. But the problem is critical and provides an excellent window onto the troubling possibilities if liberalization of air transport continues along its current path.

One of the lasting features of the air transport industry is its cyclical nature (Gialloreto 1988). In addition to being subject to disastrous downturns in business due to war, fuel price increases, and even weather problems, the airline industry is also susceptible to booms and busts that airline executives are unable, in many cases, to manage effectively. While the way in which the airlines operate in boom times is interesting in its own right, the busts are more interesting for this analysis. Imagine, for example, a city or region that depends on a single hub airport which is dominated by a single airline. Imagine further that the airline is not among the most profitable, but its management is doing what are perceived to be the right things to get the airline in very good shape. All is well until the industry experiences a downturn. Now the city or region risks losing its air transport service and the unenviable task of finding a new hub airline. Is it not reasonable for the city or region to subsidize the airline to keep it from complete collapse?

The answer, of course, from the free-traders and the dominant airlines is that subsidies only distort the market and that all else equal the weak carrier should be allowed to die, since the market will eventually adjust to provide air transport services commensurate with demand. In many ways, this argument is persuasive, but for the community and economy that relies on the failing airline, the prospect of losing it and waiting for the market to respond is neither comforting nor encouraging. The obvious difficulty lies in the fact that if one buys the argument that air transport is critical to economic growth and development in the modern global economy, then one cannot entertain the risk of losing that service. In

this manner, globalization of the economy in general makes effective liberalization of the air transport industry a more onerous task.

The other subsidization issues raises similar questions. Cross-subsidization is best described as the use of revenues generated from profitable routes to subsidize service provided on unprofitable routes (OECD 1993 and 1997). Cross-subsidy schemes are anachronistic in a liberalized economy. If the market is the arbiter of who gets service, then cross-subsidies are merely a distortion of the market and wasteful policies. Not surprisingly, airlines are not proponents of cross-subsidization, but governments find them attractive distributive policies in which citizens who use popular and profitable routes and modes of transportation, subsidize under-utilized and unprofitable routes and modes. As an issue of social policy, cross-subsidization make good political, and perhaps economic sense if they are thought of as temporary investments to foster economic development. As an issue of strict economic or financial policy, they are wasteful in that some citizens are given services below market value. Instead of making these citizens relocate or encouraging the development of alternative modes of transport, the government redistributes wealth according to political or social objectives.

The issue of cross-subsidization raises important questions for the globalization of the air transport industry. Although good arguments can be made that the economies of North America, Europe, and parts of Asia are prepared for the kind of liberalization discussed in this paper, other areas (and perhaps some regions of North America and Europe) are not ready for liberalization (Graham 1997). In fact, one might argue that the liberalization of the air transport industry as conceived by the leading air transport firms and their governments will not lead to globalization of the industry, but create even greater disparities between the haves and have-nots in the global economy.

6 THE IMPACT OF GLOBALIZATION ON LOCAL AND REGIONAL DECISIONMAKERS

Good arguments and substantial evidence can be presented to support the claim that liberalization of air transport services makes sense for most of the industrialized world. It is worth noting though that there will be some unevenness associated with this globalization and the political and economic implications should be considered and monitored carefully. With this in mind, the next section of this study presents some conclusions from two quite disparate cases. The first case involves the City of St. Louis and its efforts to at once keep TWA and expand its airport. The second case is a broader examination of the implications of liberalization for air transport services in Africa. In both cases, the concerns by policy makers are similar in that there is an overarching focus on economic development and connections with the global economy.

6.1 Globalization in the industrialized world: St. Louis and Trans World Airlines

The saga of TWA is well-known in aviation circles. The carrier was once among the most successful international airlines in the world. Along with Pan Am, TWA served America's foreign travel needs before the dramatic regulatory reforms of the late 1970s. From that point on, the airline has struggled to stay aloft, fighting what has amounted to a rear-guard action against better managed and more powerful competitors. TWA's story and the ramifications of its difficulties for the City of St. Louis paint an intriguing story about the darker side of globalization. Again, this is not to argue that liberalization is a bad thing, but that it is not without cost and pain.

In the regulated era of American air transport, TWA served as one of the nation's international airlines. It flew almost exclusively from gateway airports, flying passengers from the United States to destinations all over the world. At first glance it seems that such a strong international route structure would give TWA, and airlines such as Pan Am, a leg up against its competition in a deregulated industry. Unfortunately, the carrier's focus on international routes left it without feeder networks within the domestic US market. With deregulation the distinction between domestic and international carriers was blurred. As it turned out, Delta, United, and American were able to develop international routes more easily than TWA was able to develop domestic feeder hubs and networks.

In the fierce competition that followed domestic regulatory reform, TWA floundered, eventually filing bankruptcy and undergoing reorganization. Conditions did not improve, however, since TWA was financially unable to expand and improve its fleet. While other airlines were integrating newer, more fuel-efficient aircraft into their fleets, TWA was busy trying to keep an increasingly older, inefficient, and costly fleet in operation. As fare wars raged in the newly competitive market, TWA, whose cost structure was considerably higher than its competition, sunk further and further into debt.

TWA's predicament goes well beyond the airline itself and extends to local and regional politics. The evolution of the hub and spoke system created a hierarchy of airports across the US. Cities with hub airports were afforded much better air transport services in terms of quantity and quality of destinations, especially international destinations. Hub airports became the new gateways for global air service. Cities with hub airports enjoyed direct air travel connections to the global economy, whereas non-hub cities had less frequent and more inconvenient service to foreign destinations. TWA's hubs at New York's La Guardia Airport and St. Louis' Lambert International Airport created new and interesting political problems for these cities and regions.

Neither city or state wanted to be saddled with TWA and its myriad problems, but they also did not want to risk the loss of hub status and its economic and political benefits. Thus, TWA's fate became inextricably intertwined with local and regional political interests. This relationship has created some unusual circumstances for both the airline and the local officials. In 1992, for example, when British Airways proposed to purchase an equity stake in failing USAir, TWA and its political supporters stepped up to lobby the US Department of Transportation for special and favorable consideration of the bailout. Despite wide-spread concern by national political leaders about the prospect of increased foreign ownership of American carriers, Senate leaders from New York and Missouri argued that BA should be given the opportunity to save USAir (Newhouse 1993). This support had little to do with the Senators' concern for USAir's employees and the cities they served, but had everything to do with the fact that a revitalized USAir might acquire failing TWA and secure hub status for La Guardia and St. Louis. Unfortunately for TWA and its hub cities, the BA-USAir deal was restructured in ways that left USAir in no position to play savior for the trouble carrier.

In 1993, after it became clear that an acquisition was unlikely, the City of St. Louis moved to prevent TWA from complete collapse. In an unusual move in this era of privatization and divestiture, the City purchased TWA's 57 gates and other equipment at St. Louis International Airport for \$70 million, forgiving the airline's debt of \$5.3 million and giving

the struggling carrier \$65 million to meet its operating and other expenses. The city, desperate to protect its hub status, decided that this scheme would allow St. Louis to avoid the troubles faced by other hub cities in which airlines failed and bankruptcy proceedings paralyzed any attempt to attract new airlines (St. Louis Airport Authority 1993).

The City of St. Louis and TWA continue the struggle to maintain and enhance their hub status. Unfortunately, the efforts of the city combined with the TWA's dire circumstances make policy success unlikely. In its most recent efforts, the city has proposed an enormous expansion of its runway and terminal capacity. While the stated goal of this project is to enhance the airport and help TWA survive in the competitive global air travel market, critics of the expansion question the financial, technical, and commercial assumptions behind it. It is quite possible, for example, that TWA, which has not been able to make money in recent years while most other major carriers have achieved record profits, will actually sink under the burden of much higher landing fees and operational disruptions caused by the expansion. Ironically, recent cash infusions of up to \$26 million in pre-paid tickets by the St. Louis business community make the relationship between the city and the airline uneven. The airline very existence depended on the cash it received earlier this year. There is little the airline can do or say to go against the wishes of city decision makers who are determined to expand the airport. St. Louis is in the unenviable position of wanting to expand its airport capacity to save its hub carrier, while its efforts might actually kill the airline and saddle the city with an expensive and infeasible project.

The story of TWA and St. Louis is interesting because it highlights the difficulties associated with making local and regional policies in a liberalized global economy. In a truly liberalized market, TWA would have vanished years ago. Instead, it limped along through two bankruptcies and is alive today only because of the cash infusions noted above. Those interested in efficient markets and industries might hold up TWA as their case-in-point: the airline, despite recent efforts, is still inefficient and unprofitable (although the airline has shown some stability in recent months). Moreover, while successful carriers are expanding their global route structures, TWA is contracting and abandoning foreign destinations. Perhaps the lesson to be learned from this experience is that the market has indeed changed such that local and regional political leaders can only stave off the inevitability of failure for inefficient carriers.

This conclusion begs the critical question though of how the loss or diminution of air travel services actually affects the economies of cities like St. Louis. If, as many aviation advocates suggest, air transport links to the global economy are critical for a city or region's economic well-being, then perhaps the failure of airlines like TWA represent larger political and economic problems. This is an empirical question on which little systematic analysis has been conducted. The question is further clouded by the circulation of analysis which is motivated more by marketing than by rigorous examination of the impact of the acquisition or loss of air transport services. It is possible, however, that in most cases, cities, regions, and nations that lack quality air transport services will be at a disadvantage in competition with their counterparts who are well served, but this should not be interpreted as justification to spend scarce resources to build airports, purchase aircraft, and operate airlines, without respect for real costs (Caves 1993).

6.2 Globalization and the developing world: The African dilemma

Ironically, much of the literature on the globalization of the air transport industry is strangely silent on the subject of aviation in Africa (See OECD 1993 and 1997). Seemingly for many analysts, globalization includes only Asia, Europe, and North America, leaving South America and Africa out of the mix. A closer analysis of the likely impact of the liberalization efforts discussed earlier on the nations of Africa provides good clues about why the continent is left out of otherwise glowing recitations about the virtue of competition in air transport. Unlike, the circumstances surrounding St. Louis and TWA, in which only a single region is likely to be adversely affected, and then only temporarily as the market adjusts to meet demand, Africa lags behind the industrialized North in ways that suggest its problems are more intractable.

Africa suffers from its internal political and economic difficulties as well as a general lack of integration with the global economy. More importantly for the issue of air transport, Africa has neither the airport infrastructure or airline industry necessary for participation in a liberalized air transport market. Thus Africa poses an interesting case for policy makers and scholars alike who hope to understand the true impact of globalization. As noted earlier, liberal theories of international relations suggest that globalization of transportation links will not only reduce the probability of conflict, but also enhance the prospects for economic growth the development. Therefore, Africa emerges as a case in which the promise of liberalization and globalization can be critically examined.

Preliminary analysis suggests that Africa will not gain from the globalization of the air transport industry, especially if that globalization is defined primarily by a liberalization of the industry. In that context, the differences between Africa and the industrialized North loom ominously. While observers complain about the lack of airport capacity or the poor quality of the transportation infrastructure in some industrialized nations, those problems pale in comparison to the general situation in Africa. In some sense, Africa is starting from nearly ground zero in the development of its airlines and airports (Kapur 1995 and Woolley 1984). This necessarily places it in a difficult position when the key to enter the global economy is a commitment to liberalization and its various requirements.

The infrastructure and airlines that are now being privatized and deregulated in much of the industrialized world grew up in an era of careful protection and indulgence from national governments. Relying on arguments about national security, economic development, and social justice, governments around the world poured resources into the development of their aviation infrastructure. To the extent the economies of these states developed as well, aviation played an interactive role in the enhancement of economic growth. This is a careful distinction from the simplistic argument of aviation proponents who suggest that if one builds airports and develops airlines, his economy will magically grow and develop in ways that are impossible without air transport. A analogous and illustrative example of this logic comes from the American National Business Aircraft Association, who, as part of their "No plane, no gain" marketing promotion, published results of a study that purported to show that companies who owned their own business aircraft were more successful than companies that didn't. An interesting correlation to be sure, but it says little about causality. One could easily say that successful businesses are more likely to purchase and operate planes than failing firms, but this tells us little about the effect of plane ownership on firm performance.

Similarly, one is tempted to argue that since industrialized and newly industrialized nations, such as those in Asia, worked hard to develop air transport infrastructure and good domestic airlines, that such efforts are equally critical for the economic success of those nations lagging behind. The central question is one of sequence. It is more plausible that aviation, like other economic resources, develops simultaneous with other sectors of a growing economy. Initial government protection and public support for these aviation projects is critical since the private sector is unwilling or unable to take on the burden of paying for and managing such enormous investments. A good aviation infrastructure helps develop and is itself developed by a growing, dynamic economy. In short, aviation projects and investments are “lumpy.” In other words, you cannot build a quarter of a runway this year and wait until the resources appear or demand becomes more evident before adding the next quarter. Airports and airlines are complex and expensive operations that typically require huge investments and careful management. To this end, African nations are poorly situated to develop their aviation resources in any significant manner. More importantly though, the current trends towards liberalization place additional constraints on any efforts that might be made.

Recall that liberalization efforts include a number of provisions that are aimed at reducing the role of government, as either protector or investor. Proponents of liberalization tout the efficiency gained by privatizing state-owned airlines and airports, curtailing subsidies for otherwise failing airlines, and ending route and slot restrictions that only serve to protect inefficient domestic airlines. The empirical evidence for the benefits of liberalization is in most cases preliminary, but seems to lend support to these claims. Unfortunately, most of this evidence comes from the US and Europe, with some evidence from nations of the Pacific. These are typically industrialized nations with mature aviation industries and substantial infrastructure already in place.

The question then is how liberalization will affect the poorer, less-developed economies of Africa and Latin America. If history is any guide, the results will be dismal. This is not to say that progress in this area is impossible, but that earlier efforts to improve Africa’s aviation resources have produced woeful results. In particular, multilateral development projects have done little to effectively improve Africa’s aviation infrastructure. Similarly, private initiatives have also floundered. The International Air Transport Association (IATA), the organization of the world’s airlines, launched a program in 1980 to help developing countries airlines (Woolley 1984 and IATA 1996). Called the Program for Developing Airlines (PDNA), the program was designed to give technical and management assistance and training to airlines in the developing world. The idea is an intriguing one because it recognizes that financial assistance to build airports and purchase aircraft are likely to be wasted if pilots and managers are inadequately trained and poorly prepared to operate them. The program got off to a slow start since the airline industry was in dire financial straits generally in the early 1980s, but as that position improved, airlines from the developed world increasingly offered assistance.

After early promises and raised expectations, the commitment to such programs declined and most developing nations’ airlines found themselves virtually alone once more. What explains the initial interest in assistance and then a significant reversal? A powerful explanation, and one that raises additional questions for the future of air transport in the developing world is the nature of competition. Recall that in the early 1980s the

restrictive bilateral regime was still very much in place and as such emphasized the primacy of national flag-carriers. With such protections in place, powerful airlines from the developed world were unable to tap the markets of the developing world. Helping these less-fortunate airlines in this regime implied no competitive costs to the dominant carriers. American efforts to open the skies slowly changed this attitude by raising the possibility of more liberal international competition. In simple terms, it no longer made as much sense for the developed nations' airlines to assist the airlines of the developing world.

The proponents of liberalization would likely agree that the incentive to help developing nations' carriers has declined significantly, but they would quickly suggest that this is not all that bad. In fact, they would argue that an open skies regime with no limits on foreign ownership and cabotage will actually benefit the developing market since efficient airlines from the North will move in to offer services to meet demand. In turn, the argument goes, better service will increase economic development potential and the developing world will be on its way to more effectively participating in the global economy. Early indicators suggest that this argument is somewhat accurate, but care must be taken when drawing conclusions.

Success stories in the developing world can be found in South America where American carriers have expanded and enhanced service between the US and various Latin American countries. By utilizing code-sharing and equity investments, domestic carriers have been improved and service levels increased in many markets. Problems exist, however, and they will be more difficult to address. The greatest problem is airport capacity. As noted earlier in the case study of St. Louis, this is not exclusively a developing world problem, but resource constraints are more severe in the South and likely to create significant obstacles to timely development of aviation infrastructure.

A more intriguing problem concerns sovereignty and autonomy. Here the lines between the proponents and opponents of liberalization will be more clearly drawn. If the dominant airlines from Europe, Asia, and North America do in fact expand to offer air transport services in Africa and other parts of the developing world, it will be at the cost of the sovereignty and autonomy of those developing nations. For liberal theorists, the answer is a resounding "So what?" but for critics of liberalization and concerned political leaders of these nations, the loss of aviation autonomy, even if better services are received in exchange, is a risk they are leery of taking. It is difficult to put a value on sovereignty and autonomy, especially when objective empirical evidence of money saved, routes served, and safety standards upheld are readily available to counter fuzzy arguments about these abstract national interests. This is the important and difficult question to answer when one considers the impact of globalization of air transport.

7 CONCLUSIONS

This paper offers a rather broad stroke examination of the trends in air transport that have been variously labeled as globalization, liberalization, and open skies. The paper does not offer a definitive conclusion about the utility of liberalization, but raises the equally important questions of whether the process of liberalization, which seems to be inevitable, will actually create a more competitive air transport market and whether the liberalization process will actually create a globalized air transport industry, competitive or otherwise. The conclusions are preliminary, but suggest caution when reading about the triumph of

liberalization and competition. The relationship between airlines and governments suggests that dominant carriers will likely play a significant role in shaping the new regulatory framework, whether that is a reformulated bilateral regime or an institutionalized multilateral approach. These airlines, like all firms, are expected to pursue their own interests and call for an air transport market that allows them to maximize their profits and exploit their competitive advantage. One ramification of this trend is that local and regional political leaders will be challenged with the task of maintaining or enhancing their airport capacity in order to ensure good air transport services. As the story of TWA and St. Louis shows, this is not an easy task in a rapidly changing and dynamic market. Similarly, the trend towards liberalization suggests that political leaders in the developing world will be faced with the choice of fighting the trend and maintaining support for their flag-carriers or opening their markets and facing the uncertainties associated with attracting and maintaining quality air transport services in a highly competitive market that rewards only those carriers that contain costs by abandoning routes and services that are unprofitable. The future is not altogether troubling, but political leaders will need to proceed carefully, yet aggressively if their cities, regions, and nations are to benefit from the globalization of the air transport industry.

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**DOMESTIC AVIATION NETWORK ANALYSIS
AND AVIATION POLICY SCENARIO**

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1 INTRODUCTION

Recent tendency of globalization and /or internationalization stimulates the air-demand more and more. In Japan, the 66.9 million passengers used the domestic flights in 1995. About 56.4 million passengers, 81 % of domestic air passengers, used either of Tokyo International Airport (henceforth called as TKY) or Osaka International Airport (henceforth called as OSA) or both. Only 19 % of domestic air passengers used other local flights. The flight number of both airports reaches almost the limit of their capacity, and that of Kansai International Airport (henceforth called as KIX) opened in 1994, is also estimated to be saturated in the near future. Thus, New Chubu International Airport is being planned. Under these situations, it is needed to develop the suitable and easy tools to analyze the impact on the air passengers' flow by the construction of the new airport.

There has been many researches in the field of demand forecast under a given aviation network. Researches by Morichi et al (1993), and Furuichi et al (1993) are the examples of introducing the logit type models. However, these do not consider the strategic behavior of airlines. Todoroki et al (1992), Kita et al (1995) and Takase et al (1995) developed models to consider the behavior of airlines and passengers. These are quite interesting in the sense that they include the objective functions of both of airlines and passengers. However, they lack the approach to an "equilibria" between airlines and passengers. Ohashi et al (1996) formulated the equilibrium between airlines and passengers as the "general equilibrium" considering the aviation fee and flight frequency. Their model is very precise from the theoretical viewpoint. However, when that model is applied to the real aviation network, it may be difficult to take the equilibrium solution because it requires the quite huge size of computation. Taking these into account, the present paper aims to develop an easier analytical tool to obtain the equilibrium flow in the air transportation network.

In the real air transportation market, (1) the flow of passengers and / or goods is the resultant equilibrium in the market through strategic behaviors of transportation agencies (henceforth called as carrier) and passengers or shippers (henceforth called as user) under the governmental policies which include airport construction and its management, (2) the carrier has the perfect information about the users' behavior, but users have the limited information provided by the carrier, (3) the relationship between the carriers and users is not interactive. This situation of air transportation market constituted of the government, the carrier and the user can be regarded as the gaming so called as Stackelberg Problem. Under these understandings, Kuroda and Takebayashi (1996, 1997) developed a model to obtain the Stackelberg equilibria among carriers (airlines and railways) and passengers under given inter-regional O.D. distribution of demand. The present paper analyzes the impact of the construction of New Chubu International Airport on the air passengers' flow based on their model.

2 MODEL FORMULATION

As discussed previously, the equilibrium of the behavior of the carriers and the users can be regarded as the Stackelberg equilibria in the transportation market. The Stackelberg planning problem is characterized as follows;

- 1) There are two types of players in the game; the leader and follower.
- 2) The leader has the perfect information about the follower's behavior, while the follower must behave under the constraints of the strategy provided by the leader.

The carriers, in this paper, are regarded as the leader, and the users as the follower. It is notified that in the Japanese domestic transportation market, the airlines and the railway company take the role of the carrier, because the long distance bullet train is a competitive mode to the air transportation. The structure of the problem is shown in Figure 1.

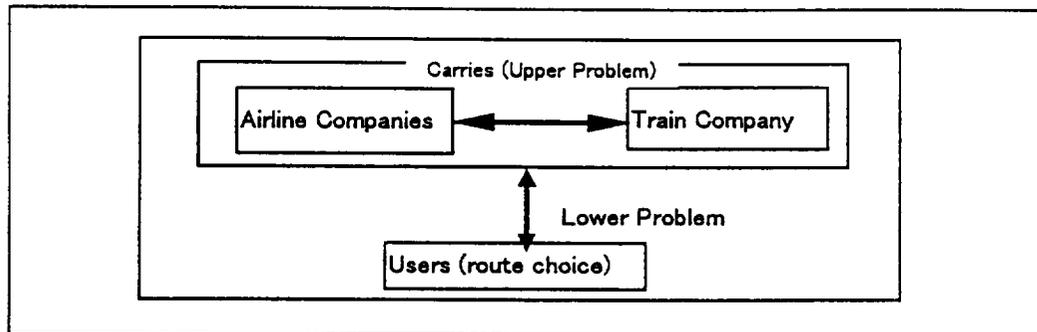


Figure 1 The Structure of the Problem

In the real world, Nash-type equilibrium between the airline company and the railway company must be explicitly discussed. However, since the present paper focuses on the influence of the strategy of the airline company on the domestic air transportation market, the railway company is treated as the player who does not change his present service level even if it plays a role as an alternative transportation mode.

2.1 Premises and Assumptions

In modeling of the airlines' and the passengers' behavior, followings are assumed and premised;

- 1) Airport locations and its capacities are a priori given as the policy scenario by the government.
- 2) The railway network including that of the bullet train (Shin-kan-sen) and the train schedule are given, and the railway company does not change its train schedule and fare.
- 3) The capacity of train is assumed to be large enough to carry all the passengers between any origin and destination.
- 4) Railway stations are assumed to locate at the centroid of each zone.
- 5) The access and the egress to the bullet train station in the zone are limited by the ordinary train, while those to the airport are available by either of the ordinary train or the limousine bus.
- 6) The O.D. distribution of passengers is a priori given. This means that the present paper does not treat the long-term equilibrium of the system, but the short-term flow equilibrium.
- 7) Passengers can choose whichever the railway or the airway.
- 8) Competition among air carriers is not explicitly treated, but implicitly considered by introducing a load factor.
- 9) The airlines can decide their airway service route, the craft capacity, the fair, and the

scheduled frequency under the constraints of the airport's capacity.

- 10) The purpose of the airlines is assumed to maximize their net revenue, while the passengers behave to minimize the total travel time, total travel cost, or the total generalized cost.
- 11) At the hub airport, the connecting time necessary for transit passengers is assumed constant. This means the flight schedule is planned to satisfy this constraint.
- 12) The airfare per person for each airline service route is assumed constant. This means there is a regulation on airfare by the government in Japan.

2.2 Airline's Behavior

The airlines can decide their strategy to maximize their net revenue under the perfect information about the passengers' behavior, but their scheduled flight frequency is constrained by the airport capacity. Their revenue comes from the fare of total passengers of their flights, and they expend the running costs such as depreciation of crafts, fuel, crew expenditure, and so forth, and the airport costs such as landing charge, rental fee of terminal facilities. Thus, referring to Figure 2, the objective function of the airline and the constraints are given by

$$\max B(y_m^l) = \sum_i \sum_j \sum_{l \in La} \left(\sum_k AP^l \cdot \delta_k^l \cdot x_{ijk} \right) - \sum_{l \in La} \sum_m y_m^l \cdot RC_m^l - \sum_{l \in La} \sum_{h \in Ha} \sum_m \delta_h^l \cdot APC_m^h \cdot y_m^l \quad (1)$$

$$\text{s.t.} \quad \sum_{l \in La} \sum_m \delta_h^l \cdot y_m^l \leq CAP^h \quad (\text{for } \forall h \in Ha) \quad (2)$$

$$y_m^l = y_m^{\hat{l}} \quad (\text{for } \forall l, \hat{l} \in La, \forall m) \quad (3)$$

$$y_m^l \geq 0 \quad (4)$$

$$\text{and } \boxed{\text{passenger's behavior}} \quad (5)$$

where

L : a set of links

La : set of airway links ($La \in L$).

k : a route consisted of a series of links.

l : a link as an element of a route with its direction.

\hat{l} : same link as the link l with opposite direction of l .

i, j : origin and destination zones.

x_{ijk} : travelers volume per day from the zone i to the zone j using the route k .

AP^l : airfare per person for the link l .

δ_k^l : Kronecker's delta defined as

$$\delta_k^l : \begin{cases} 1 : \text{the link } l \text{ is included in the route } k \in Ka \\ 0 : \text{others} \end{cases}$$

δ_l^A : Kronecker's delta defined as

$$\delta_l^A : \begin{cases} 1 : \text{the link } l \text{ is an airway} \\ 0 : \text{others} \end{cases}$$

Ka : set of routes including airway links.

RC_m^l : one flight operational cost of a craft of size m for the link l .

APC_m^h : one flight airport charge of a craft of size m at the terminal h .

y_m^l : daily service frequency of crafts at the link l .

δ_h^l : Kronecker's delta defined as

$$\delta_h^l : \begin{cases} 1 : \text{terminal } h \text{ is included in the link } l \\ 0 : \text{others} \end{cases}$$

CAP^h : capacity of terminal h , expressed by maximum flight number.

H : a set of terminals.

Ha : a set of airports ($Ha \in H$).

The constraint Eq.(2) means that the total flight number at the airport h does not exceed the capacity of the airport h . The constraint Eq.(3) means that the flight frequency of the link l is the same number as that of \hat{l} . The constraint Eq.(4) means the non-negative number of each flight frequency.

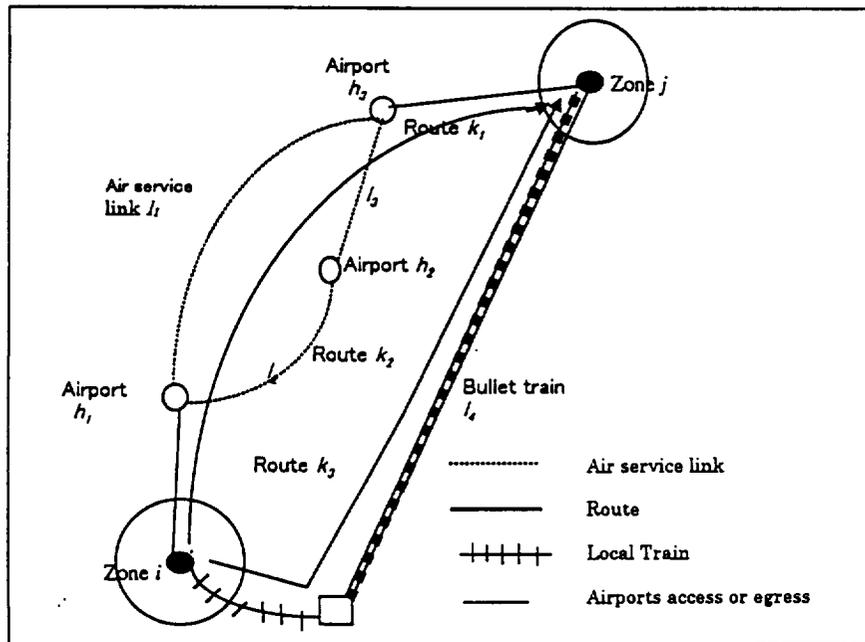


Figure 2 Concept of Transportation Network

2.3 Passengers' Behavior

The passengers can choose either of the airway or the railway consulting their preferences under the flight schedule and the capacity of flight provided by the air-carriers and those by railway companies. The total travel time for aviation passengers considered is shown in figure 3.

The passengers may prefer to minimize (1) the total travel time, or (2) to minimize the total

travel cost, or (3) to minimize the generalized cost. K. Kuroda and M. Takebayashi (1996) investigated above three criteria for air passengers, and concluded that the criterion of the minimum total travel time was most appropriate to explain the air passengers' behavior.

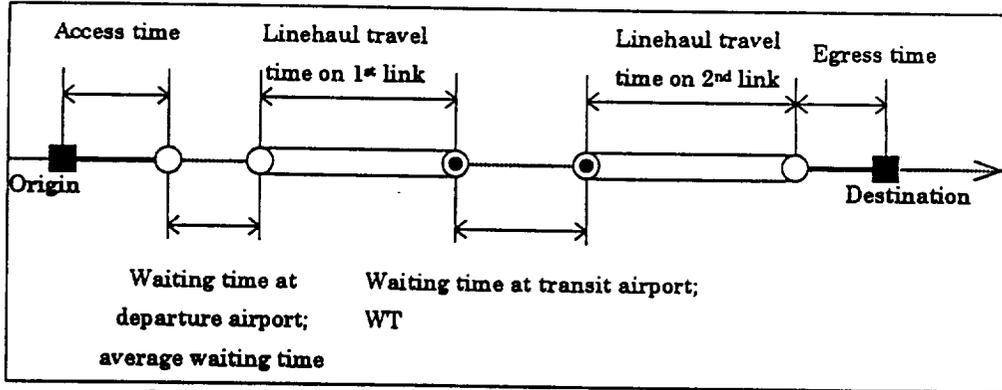


Figure 3 The Content of Aviation Passengers' Travel Time

Therefore, the present paper employs this criterion. It is formulated as follows;

$$\begin{aligned} \min T(x_{ijk}) &= \sum_i \sum_j \sum_k x_{ijk} \cdot t_{ijk} \\ &= \sum_i \sum_j \sum_k x_{ijk} \left\{ \delta_k^A (t_{ijk}^{ae} + \sum_{l \in L} \delta_k^l \cdot t^l + \sum_{l \in L} \sum_{h \in H} \sum_m \delta_{2k}^l \cdot \delta_{2h}^l \cdot \frac{OT}{2 \cdot \sum_m y_m^l} + \sum_{l \in L} \sum_{h \in H} \delta_{3k}^l \cdot \delta_{2h}^l \cdot WT) \right. \\ &\quad \left. + \delta_k^R (\sum_{l \in L} \delta_k^l \cdot t^l + \sum_{l \in L} \sum_{h \in H} \sum_m \delta_{2k}^l \cdot \delta_{2h}^l \cdot \frac{OT}{2 \cdot \sum_m y_m^l}) \right\} \end{aligned} \quad (6)$$

$$\text{s.t.} \quad \sum_k x_{ijk} = X_{ij} \quad (7)$$

$$\sum_i \sum_j \sum_k \sum_m \delta_k^l \cdot x_{ijk} \leq y_m^l \cdot CAP_m^l \cdot \lambda_m^l \quad (8)$$

$$x_{ijk} \geq 0 \quad (9)$$

where

x_{ijk} : passengers' volume from zone i to zone j using route k .

X_{ij} : the volumes of OD passengers between the zone i and the zone j (person/day).

CAP_m^l : the aircraft's capacity of a craft of size m at the airline or railway service route

l (person/craft).

WT : waiting time for transit at the airport (assumed as a constant value).

δ_k^A : Kronecker's delta defined as

$$\delta_k^A : \begin{cases} 1 : \text{route } k \text{ includes airlines} \\ 0 : \text{others} \end{cases}$$

δ_k^R : Kronecker's delta defined as

$$\delta_k^R : \begin{cases} 1 : \text{route } k \text{ includes railway} \\ 0 : \text{others} \end{cases}$$

t_{ijk} : travel time from i to j at route k .

t_{ijk}^{ae} : the total access and egress time at the route k between the zone i and the zone j (min).

t^l : the line haul travel time at the link l (min).

OT : the opened time of the terminal (hrs/day).

λ_m^l : the load factor of the craft of size m at the link l .

δ_{2k}^l : Kronecker's delta defined as

$$\delta_{2k}^l : \begin{cases} 1 : \text{link } l \text{ is the first link included in route } k \\ 0 : \text{others} \end{cases}$$

δ_{3k}^l : Kronecker's delta defined as

$$\delta_{3k}^l : \begin{cases} 1 : \text{link } l \text{ is the second link included in route } k \\ 0 : \text{others} \end{cases}$$

δ_{2h}^l : Kronecker's delta defined as

$$\delta_{2h}^l : \begin{cases} 1 : \text{terminal } h \text{ is included in the link } l \\ 0 : \text{others} \end{cases}$$

The constraint Eq.(7) means that the total number of passengers using all routes between the zone i and j must be equal to its O.D. volume of passengers, and Eq.(8) gives the constraint that the air passengers at any air transportation link must be less than equal to its total capacity, and Eq.(9) gives the non-negative constraint for the variable x_{ijk} .

3 MODEL TEST BY PASSENGERS' BEHAVIOR

3.1 Numerical Conditions

Kuroda and Takebayashi (1996) discussed the model performance by applying it to domestic transportation network in Japan, and concluded that the minimum travel time criterion can well explain the behavior of passengers. However, they suggested that the constant waiting time for transit passengers assumed in their model has given a discrepancy for local line passengers. Then, in the present paper, the passenger behavior model is appropriately modified as discussed previously. Therefore the present paper again discussed the modified model performance for estimation of passengers behavior. In numerical computations, following data is used;

3.1.1 OD Zones and OD Distribution of Passengers

Prefecture governmental domain is employed as the OD zones (Table 1), and each of the OD pair of passengers between every two prefectures is used as the data based on the Survey of Passengers Movement by the Ministry of Transport of Japan in 1991 (Ministry of Transport, 1991). This OD distribution is assumed not to be influenced by the charge of the airline policy, because the OD distribution is mainly determined through socio-economic activities in the region. It is, however, noticed that the volume of air passengers, that is, air demand, is, of course, influenced by the air line policy.

Table 1 OD Zones

1	2	3	4	5	6	7	8	9
Hokkaido	Aomori	Ibaragi	Toyama	Shiga	Tottori	Tokushima	Fukuoka	Okinawa
	Iwate	Tochigi	Ishikawa	Kyoto	Shimane	Kagawa	Saga	
	Miyagi	Gunma	Fukui	Osaka	Okayama	Ehime	Nagasaki	
	Akita	Saitama	Gifu	Hyogo	Hiroshima	Kochi	Kumamoto	
	Yamagata	Chiba	Shizuoka	Nara	Yamaguchi		Oita	
	Fukushima	Tokyo	Aichi	Wakayama			Miyazaki	
		Kanagawa	Mie				Kagoshima	
		Niigata						
		Yamanashi						
		Nagano						

3.1.2 Airports and Service Route Network

Since, in Japan, the airline policy is more or less restricted by regulation of the central government, the airway routing and service frequency might not be optimal for air carriers. Thus, the comparing with the existing airway routes and frequency and computation results by the model is nonsense. Therefore, in the present paper only passengers behavior is examined under the existing policy of airlines. Airports considered in computation are the first and the second class airports regulated in Japan, those and airline service routes are shown in Figure 4. It is noticed in the figure that Kansai International Airport (KIX) was opened in 1994, and extension of Tokyo International Airport (TKY) will be completed in 1997 which will supply more capacity than the present. Therefore the model test was carried out for the condition before KIX was opened. However, simulation of airport policy scenario in the succeeding chapter is carried out after KIX is opened and extension of TKY is finished. In Table 2 is listed the capacity of main airports.

3.1.3 Aircraft and Costs

The aircraft type used for the domestic service, their capacity and their operation costs are listed in Table 3. The airport charge is also listed in the same table. The operation cost of aircraft is referred to the Airline Statistics in 1991 (Ministry of Transport, 1991), and it includes the redemption cost of aircraft as an average value. The airport charge of all the airport considered is the same. This is referred to the Airline Statistics in 1991 (Ministry of Transport, 1991). Load factor of all crafts is assumed as 0.7, which is considered as average value in all service routes.

3.2 Examination of Passengers' Behavior

As previously mentioned, model test is carried out only for passengers' behavior under the air service network in 1991. The computation results by the model are compared with the Airline Statistics in 1991 (Ministry of Transport, 1991).

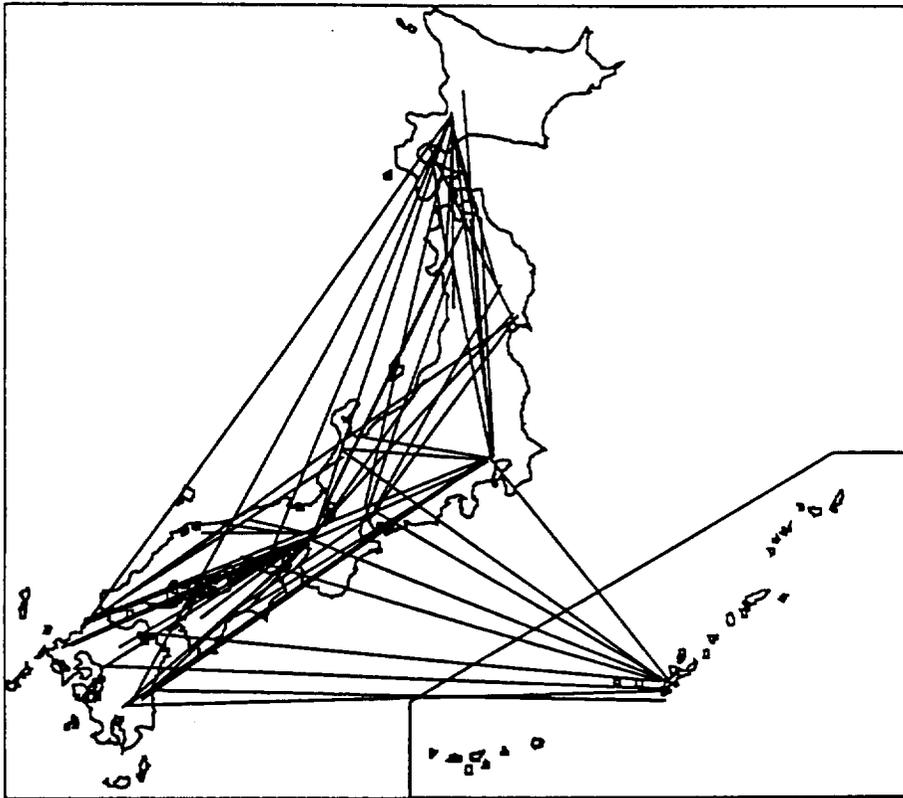


Figure 4 Air Service Routes

Table 2 Capacity of Main Airports (1991)

Airport	Capacity (craft /day)
TKY	400
OSA	300
NGY	240
SAP	300

Table 3 Capacity, Operational Cost and Airport Charge

Type	Capacity (person/ craft)	Operational Cost (thousand yen/ flight)	Airport Charge (thousand yen/ flight)
B747	569	6,037	475
DC10	318	4,750	374
B767	288	2,815	221
A300	308	3,187	251

The air passengers' volume of all service routes estimated by the model and those by the statistics are shown in Figure 5.

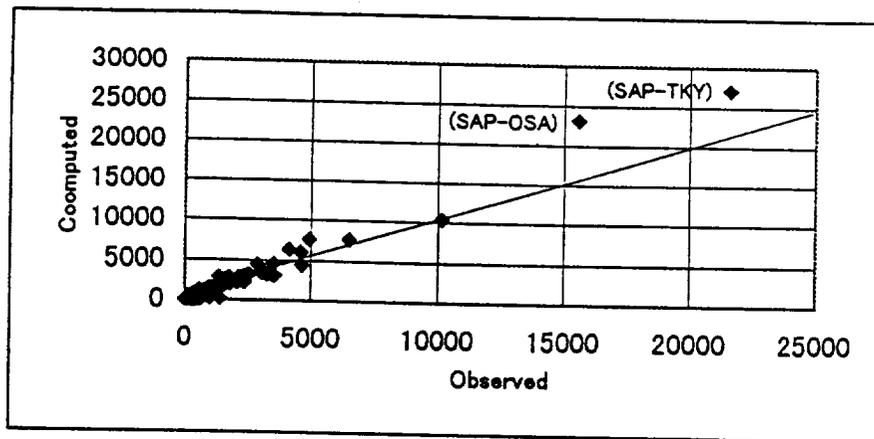


Figure 5 Comparison of Air Passengers Volume

The figure shows the model can well explain the behavior of passengers who chose the air transportation. The correlation coefficient is 0.984. However, it can be seen that there are some local service routes that can not be explained by the model. Those routes are the local to local route whose flight service frequency is relatively small than the main routes. The lower service frequency results in the longer interval time at the airport, which is defined as the average waiting time in the model. Therefore, the model estimates that passengers of the region that has an airport with relatively lower frequent service choose the railway. The model should be further improved to diminish this point in future. As already discussed, the model test is carried out under the given air service routes which are more or less regulated by the government. Then in order to investigate how much is the difference of air carrier's behavior between the computed (assumed non-regulated free market) and the present is compared. The results are shown in Figure 6. As can be seen in this figure and Figure 5, the real service routes in 1991 employed by the airlines were almost optimized in the sense that they maximized their net revenue. These results may suggest that if air transportation market is completely deregulated, air carriers may withdraw from these local service routes. This will be further discussed in the succeeding chapter.

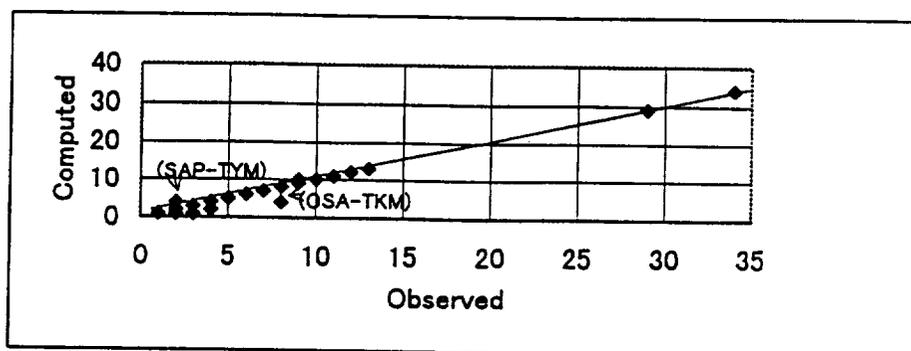


Figure 6 Comparison of Service Flight Frequency per Day

4 SIMULATION OF AVIATION POLICY SCENARIOS

As stated in the previous chapter the extension of Tokyo International Airport (TKY) is completed and extension of Kansai International Airport (KIX) is now being extended, and further a new international airport is planned to open in 2010 in Chubu Region, central part of main island of Japan, instead of closing of existing Nagoya International Airport. This is temporarily called as New Chubu International Airport (NCB). KIX and NCB are the offshore airports and their locations are not so far from existing Osaka and Nagoya International Airports, respectively. Corresponding to extension of KIX, there is some opinion of closing of OSA airport, which is located at the urbanized area in Kinki Region, because serious noise problem has been induced in the surrounding area.

Under these circumstances, this chapter discusses the influence of these plans and opinions on the air carrier's strategy in the domestic transportation market and flow of air passengers by scenario simulation using the proposed model. In the scenario simulation complete deregulated air transportation market is assumed and the crafts' capacity employed and costs are also assumed as same as the present, but the estimated OD distribution of passengers in 2010 is used. In numerical computations, the annual growth ratio of the domestic O.D. passengers from 1991 to 2010 is assumed as 1.0% according to the Air Statistics (Ministry of Transport, 1991). This leads the total of domestic O.D. passengers in 2010 as 108.83 millions (Figure 7). The O.D. distribution in 2010 is estimated based on this annual growth ratio and the present OD patterns. Four cases of scenario for discussion are considered as listed in Table 4.

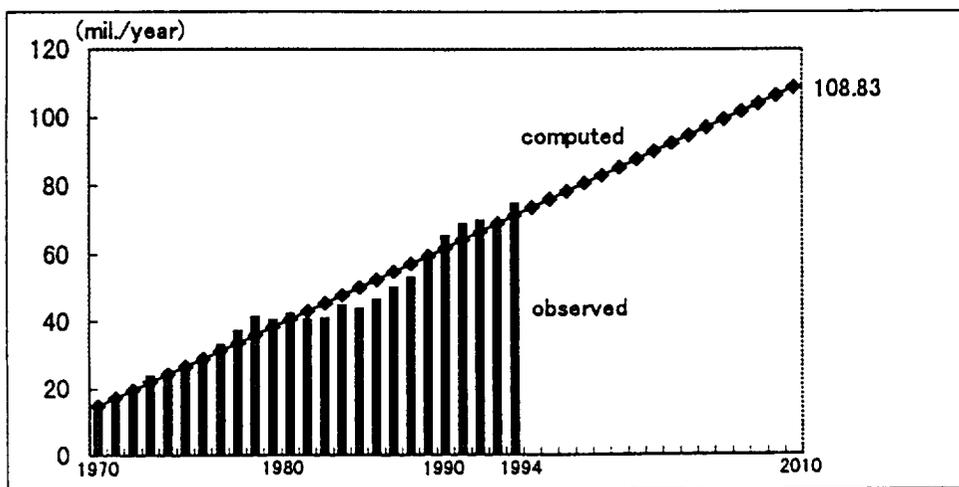


Figure 7 Comparison of Total Volume of OD Passengers from 1970 to 2010

Table 4 Conditions of Airport Capacity

Case	TKY	OSA	KIX	Chubu
Case 1	800(extended)	300(present)	200(present)	None
Case 2	800(extended)	300(present)	200(present)	300(constructed)
Case 3	800(extended)	None	500(extended)	300(constructed)
Case 4	800(extended)	None	500(extended)	None

The first scenario is Case 1 that assumes that extension of TKY is finished but KIX's extension is not finished and others are same as the present situation. The second scenario is Case 2 which assumes that Case 1 plus New Chubu International Airport (NCB). The third scenario is Case 3 that assumes that OSA is closed and NCB is opened and extension of KIX is finished. The last scenario is Case 4 that assumes that NCB is not opened yet but others are same as Case 3.

4.1 Influence of Open of New Chubu International Airport

Since New Chubu International Airport (NCB) is planned to be constructed at the offshore island where is not so far from the present Nagoya International Airport (NGY), no influence on other airports is anticipated but only change will be shift of the function of the present NGY to NCB. It is true when we see Table 5 that lists the computed results of four cases. In this table, carriers' net revenue is normalized based on Case 1.

Table 5 Impact of the Construction of Chubu New International Airport

Case	Carrier's Net Revenue	Total Aviation Passengers (thousand person/ day)	Average Travel Time (min./person)
Case 1	100	276.2	222.94
Case 2	100	276.2	222.94
Case 3	110	278.1	219.86
Case 4	110	278.1	219.86

Comparing with Case 1 and Case 2, the influence of NCB on carrier's net revenue, total volume of air passengers and average travel time of passengers can not be seen. This can be also concluded from Figure 8, which shows the total volume of air passengers of each airport.

Figure 8 teaches us that the construction of NCB and in Fig. 8 and Fig. 9 the close of NGY gives no influence at all on air market. It is also notable that TKY will invite much more air passengers than other airports reflecting the greater increase of OD volume of the hinter region and transit passengers.

This means that airlines proper to take the strategy of Hub-and-Spoke type network of their service route in the free market for more cost-effectiveness.

4.2 Influence of Close of Osaka International Airport

Influence of close of OSA can be examined by comparing with Case 1 and Case 3. From Table 5 it will be estimated that close of OSA will result in increase of net revenue of airlines and decrease of average travel time of passengers. Comparing with Case 2 and Case 3, only change induced by close of OSA is the shift of function of OSA to KIX. When OSA is closed passengers using OSA may shift to KIX, and KIX will be functioned as the Hub airport more than the present as can be seen in Figure 9.

() shows the ratio of landing frequency to airport capacity.

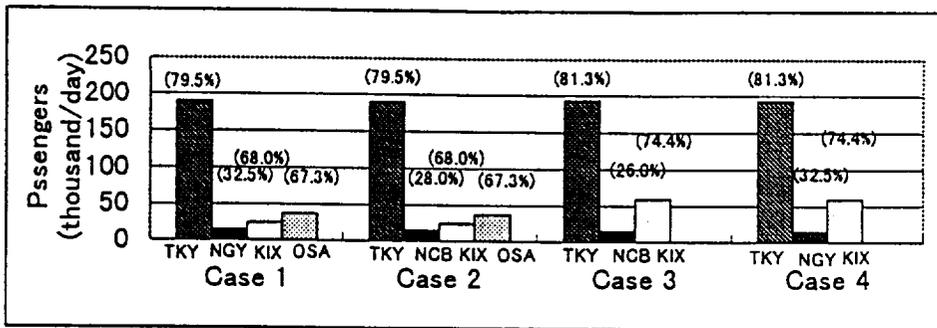


Figure 8 Comparison of Total Volume of Air Passengers at Each Airport

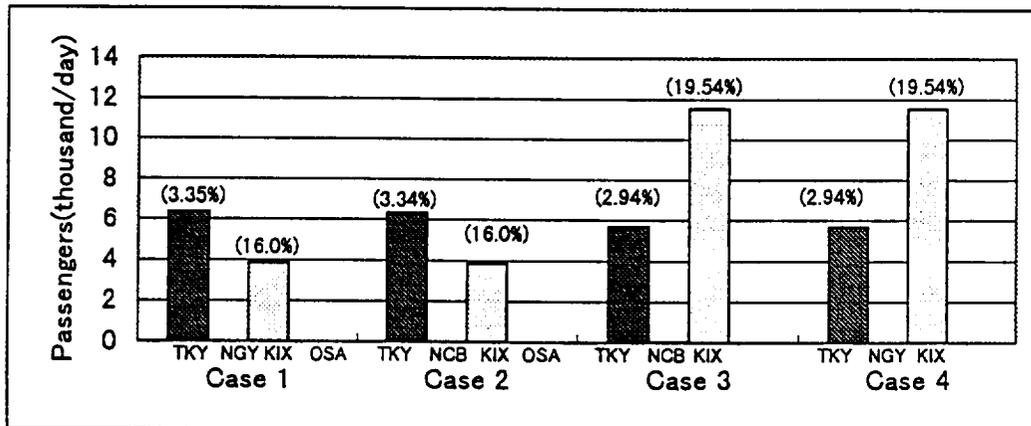


Figure 9 Comparison of Transit Passengers at each Airport

From these it is concluded that close of OSA will improve not only the net revenue of airlines but also the average travel time of passengers by strengthening the Hub-function of KIX. This conclusion may suggest that the extension of KIX will invite change of airlines' routing strategy so as to collect their network from OSA to KIX in the regulation free market because this change is better for both of airlines and passengers. In order to examine this hypothesis, Case 4 is carried out. Results are discussed in the next section.

4.3 Influence of Extension of Kansai International Airport

It is easily anticipated that the extension of KIX will at least influence on existing Osaka International Airport because those are located very closely. In the previous section this is suggested. In fact, the results of Case 4 shown in Table 5, Figure 8 and Figure 9 say that the extension of KIX will invite all airlines to KIX from OSA in order to make the Hub-and-Spokes type network which is more cost-effective for airlines and consequently it gives more convenient service for passengers. This may be true if regulation free market is accomplished and airlines are assumed to make consortium. However, in the real market, each of airlines may behave to maximize his own net revenue if independent service is more profitable than making consortium. Therefore some airlines may serve at OSA and others at KIX even if KIX is extended. Unfortunately the present paper do not analyze so-called Nash-type Equilibrium between airlines. This is the future problem remained in the present

paper.

5 CONCLUSION

The present paper proposes a tool to analyze so called as Stackelberg equilibria between air carriers and passengers in the domestic transportation market, and examines the model for passengers' behavior by comparing with observed volume of passengers and the computed ones by the model. The results say that the model can well explain the passengers' behavior.

The paper also analyzes the influences of some aviation policy scenarios, which include the extension of Tokyo and Kansai International Airports, the construction of New Chubu International Airport, and the close of Osaka International Airport. Even the present model gives much information about future conditions under those policy scenarios, these are based on some assumptions and premises which must be improved. One of those is the assumption of non-competitive situation among airlines in the market. When this is considered in the model, a special computation algorithm should be developed. Another improvement is about the cost function of airlines. The present model does not give the detail cost function, which makes us impossible to analyze the change of airport management policy such as landing cost and terminal rental fee and so forth.

The model also does not consider the international air passengers' behavior because the structure of international aviation market is supposed not to be the same as the domestic one. Therefore, a different approach to the international aviation market is needed. This is the issue for future analysis of this study.

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Spill Modeling for Airlines

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Abstract

Spill models estimate average passenger loads when demand occasionally exceeds capacity. Such models have been in use for over 20 years. The shape of the distribution of demand is discussed from both theory and observation. Sources of variance are identified and calibrated. Measurement problems and techniques are discussed. Two alternate spill formulas are presented based on Normal distributions of demand. A revision is presented which responds to changes in process caused by computer reservations systems and revenue management. The concept that spill losses should be valued at discount fares is discussed. The recapture of spilled demand is presented as well as when such a phenomenon is relevant. Comparison of various sources of error is included. Finally, the use of spill models "in reverse" to imply demand from load is shown to have poor accuracy. The paper is meant to offer to the literature a reference for basic use. It is the result of 15 years' involvement in spill model derivations, calibrations, and applications.

1. INTRODUCTION

Spill is the average passengers per departure lost off a group of flights because demand sometimes exceeds capacity. The group of flights can involve a flight leg for a month, season, or year. Groupings can involve one leg, a small group of legs reassigned from one fleet type to another, or all the legs served by a single aircraft type in a fleet. The spill model has been used widely for over 20 years within the airline industry. However, there has been no commonly available publication discussing its use. This paper attempts to put into the record the formulation, its calibration, and some issues of use for airline analyses.

The basic idea behind spill is that demand for a group of flights can be represented as a distribution about a mean. The integral of this distribution is the "fill" rate for seats on an aircraft. This is shown in Figure 1. The integral of the fill rate beyond a truncating capacity is the spilled demand. While spill is the term usually calculated, the model is commonly employed to estimate the difference in spill between two possible capacities. This is the fill rate for the extra seats. Perhaps the "spill" model should have been named the "fill" model. Time and tradition prohibit this nomenclature, but spill model performance is judged by its performance in estimating fill.

The discussion below begins with the characterization of the demand distribution. When is it Normal and why? Development continues with two formulas for calculating spill when the distribution is close to Normal. Discussion then maintains that the appropriate fares to apply when valuing spill are discount fares. Arguments are put forth that the complications of the

recapture of spill often can be avoided. Finally, discussion discourages of the use of the spill “in reverse” to estimate demands from observed loads.

2. UNDERLYING STATITICAL MODELS FOR DEMAND DISTRIBUTIONS

The idea behind spill is that the demand for a series of departures has a distribution about its mean. The most central case in the airline business is the distribution of demand for a flight over a month. For example, the demand distribution for the set of 30 executions of the 9:00 flight from Seattle to Chicago during the month of April.

The amount of variation in the distribution can be measured by the ratio of the standard deviation to the mean. The convention within the airline industry is to refer to this ratio as the “K-factor” [DeSylva, 1976].

One source of the variation in demand is pure randomness. Imagine that 1 million people in Seattle are candidates to fly to Chicago at 9:00. Each day they flip a coin with a one in 10,000 chance of coming up heads. The probability distribution for such a series of Bernoulli trials would have a mean of 100, a K-factor near 0.10, and a shape like a 10th order Gamma.

With demands the size of an airplane, the Gamma shape is almost Normal. With smaller demands the shape is more skewed and wider, as show in Figure 2. The small demand case might be appropriate for first class seats. This one-day spill model applies for revenue management planning. The motivation for the Gamma shape is that one can estimate the probability of heads, but cannot avoid the random variations in how many heads result from 10,000 coin flips. With perfect estimate for the probability of heads, K-factors for a planeload of demand are near 0.10.

The spill model for a month includes overwhelming further variations. These come from the cycles of demand through the days of the week and throughout the weeks of the month. The cyclical variations correspond to changing the probability of heads on the coin day-by-day. It would be higher on Friday, and lower on Wednesday. For a single flight for a month, cyclic variations alone are enough to create a K-factor of 0.30. Cyclic variations are larger than the random variations, except for small demands such as first class. When cyclic variations are from several sources, or when they capture uncertainty in the estimate of demand, they are most naturally Normally distributed. Since total variation is a combination of cyclic and random sources, the shape must in theory be a compromise between the Normal and Gamma with the Normal being predominant.

Further cyclic variation occurs when considering not one flight leg but all the legs assigned to an aircraft in a day. Still higher values apply for all the legs flown by one fleet type for the month, or by a fleet type over the 12 months of a year.

Proprietary data on demand distributions has been reviewed covering a large number of cases. Data has come from U.S., European, and Asian airlines covering both domestic and

international flying. Data from 15 years back has been examined, as well as data nearly current. Most data has been daily onboard loads, but analysis has also been done on reservation system bookings. Problems with the data are discussed below, but the overall conclusions seem to be supported by most cases.

The primary conclusion is that the demand distribution is as close to Normal as anything else. Considering the multiple sources of variation, the central limit theorem would lead us to expect this outcome.

The second most important conclusion is that K-factors are surprisingly constant across widely differing market types. Furthermore, the increments of variance seem statistically independent. Table 1 presents the results of studies of the cyclical components of K-factor. The random component is reserved for the subsequent paragraph. Table 1 says the day-of-month variation produces a K-cyclic of 0.30. Broadening this to the flights that would be assigned an incremental aircraft raises the value to 0.35. For instance, this would be the variation among 4 legs transferred from service by small aircraft when one additional large aircraft becomes available. This variation is driven by changes in demand by time-of-day. The K-factor for an entire fleet adds the spectrum of demands a fleet type is expected to serve. Usual circumstances would see a rise to 0.44 for this effect. The variations across the months of a year would drive this K-factor to a total of 0.48. Finally, planning studies often accept an additional uncertainty in the forecast of the mean demand of 20% or more. This can bring the total cyclic K-factor up to 0.52. This addition is not presented in Table 1, since it is not an observed variation.

Table 1: Typical K-cyclic Values

<u>case</u>	<u>Day</u>	<u>Month</u>	<u>Season</u>	<u>Year</u>
Flight Leg	0.00	0.30	0.32	0.36
Aircraft Increment	0.18	0.35	0.37	0.40
Fleet	0.32	0.44	0.45	0.48

Random variations add very little to these cyclical components. Random variance is low for demands of 100 or so. If everyone traveled alone, the standard deviation would be roughly the square root of the demand. However, the (root mean square) average group size is closer to 2, so the standard deviation is the square root of twice the demand. This increases a K-cyclic of 0.30 to a total K-factor of 0.33 for a demand mean of 100.

For small demands such as first class, the random variance is large and the demand distributions are not Normal. For demands below 3, the monthly K-factor can be above 1.00 and the shape can approach a simple exponential distribution. Monthly total K-factors in Figure 3 show a decline from high values at low demands toward a asymptote at high demand. Figure 3 can be reproduced using detailed flight leg data.

Direct calculation of variance is difficult. Even with perfectly clean data, a month's worth of data points gives a poor estimate. Unfortunately, the data are far from clean. Loads and bookings are truncated by capacity. Low loads are often the result of flights with delays or

weather complications. Finally, high loads are sometimes the result of the cancellation of some near-by flight. These distortions focus on the tails of the distribution. Unfortunately, the tails of the distribution would provide much of the information about the size of variations, if the data were clean.

Practical calibrations of K-factor use the median to approximate the mean, and the distance from the median to the 25%ile observation to estimate the standard deviation. This gives up about half the formal statistical efficiency, but produces better results on real data. This has been tested by simulating clean data and simulating the usual distortions from truncation and delayed or canceled flights. The simulated distributions closely resembled real data. However, with the simulations the “true” underlying K-factors were known. Estimates using the 25%ile and 50%ile loads capture the K-factors underlying simulations over useful ranges of K. A practical fit that works using the standard spill formulas even for smaller first class cabins is:

$$K\text{-factor} = (\text{Load}_{50\%ile} - \text{Load}_{25\%ile} + 1) / (0.674 * \text{Load}_{50\%ile}) \quad (1)$$

Calibrations of K-factor are best done in months with low load factors. Averages over several months are needed, even for clean data. Under few circumstances can the K-factor for an individual flight leg be estimated accurately. However, similar markets have similar K-factors, and values seem to be constant across a surprisingly large range of market types. Where data is unavailable, the values from Table 1 are often used.

K-factors for markets that are purely local and purely one kind of traffic are up to 20% higher than indicated in Table 1. Most data used for calibrations comes from flight legs with a mix of business and pleasure travel, and a mix of local demand and demand connecting beyond the local city-pair. There is imperfect correlation between the cyclic variations of demand for business and pleasure or in different city-pairs. Over a broad range of mixes, the common K-factors of Table 1 result. With data that allows separate analysis of components of the total demand, K-factors for the components are seen to be higher.

3. SPILL FORMULAS

Presentations of spill model formulas date at least as early as 1976 [Shlifer and Vardi, DeSylva]. $P(x)$ is defined as the probability P of demand x . $P(x)$ is Normally distributed with mean μ and standard deviation σ . $P(x) = N(\mu, \sigma; x)$. For truncating capacity C , the number of spilled passengers is $(x-C)$ and the total spill $S(C)$ is

$$S(C) = \int_C^{\infty} (x - C) \cdot P(x) dx = \sigma \cdot N(0,1; B) - \sigma \cdot B \cdot (1 - \Phi(0,1; B)) \quad (2)$$

Where $\Phi(0,1;B)$ is the cumulative Normal, and $B = (C-\mu)/\sigma$.

This formulation proved awkward in practice. It represented a small difference of two larger numbers and required accuracy in calculating N and Φ . There was no explicit formula for Φ , so a 5- or 7-term approximation had to be used. This made the formula difficult for spreadsheets and relegated spill calculations to table lookups or use within larger scientific language programs.

A simplification was made using the common logit approximation of the cumulative Normal [Swan]. This was not accurate enough for Φ in calculations using (2), but it allowed an alternative derivation. $F(s)$ was defined as the fill rate for seat s . The fill rate was the probability that demand equaled or exceed s . For $b = (s-\mu)/\sigma$,

$$F(s) = 1 / (1 + \exp(1.7 \cdot b)) \quad (3)$$

The integral of the fill rate for all seat counts above capacity C gave the spill value:

$$S(C) = \int_B^{\infty} F(b)db = (\sigma / 1.7) \cdot \text{Ln}(1 + \exp(-1.7 \cdot B)) \quad (4)$$

A further extension provides the displacement rate D . Displacement is the incremental spill for an addition of one customer a day to the average demand μ :

$$D = S/\mu + (C/\mu) * F \quad (5)$$

Displacement values are higher than fill values because an added customer is more likely to show up on a peak flight, while an added seat is added equally on all flights.

The simpler logit formulation meant spill could be coded into spreadsheets. This increased the ease and frequency of use. Use now ranges from aircraft assignments to a schedule for a month, to studies of seating configurations, to the costs of marketing promotions, and most critically to fleet planning. Most major North American airlines employ this formulation, as well as several major carriers in Europe and Asia. Other airlines maintain equivalent formulations using Normal or Gamma distributions. Another distribution that should be explored is the Log-Normal distribution. Comparison of these various derivations is beyond the bounds of this discussion. It represents much-needed research.

Spill can be calculated numerically using any reasonable distribution as the underlying description of variations in demand. Earlier discussion of demand distributions suggests that the Gamma may be the most appropriate for small demands and small groups of flight legs while the Normal may be best for broader applications. In any case, decisions are almost always based on the difference of spill between two capacities. This is the fill rate for the incremental seats. For typical demands, numerical differences between Gamma, Normal, Log Normal, and Logit versions compared by incremental fill values are small. Such differences are overwhelmed by uncertainty in the estimate of the K-factor or other parameters, which will be discussed later.

4. REVISIONS

K-factors received a modest modification in treatment in 1983 [Swan]. Before then, K-factors were treated as independent of demand size. This implied that all variation was driven by cyclic factors. The random component was neglected in both discussion and estimation. A single K-factor for all fleet planning applications allowed the spill model to be a table lookup based on demand factor (demand divided by capacity) alone.

Recognition that there was a random component to variations explained some of the differences between very large and small aircraft and between total demand and demand for smaller component cabins. Revised versions of the spill model employ K-factors including both cyclic and random components, as discussed in the earlier section. Cyclic variations do not depend on the size of the demand, but only on the case being studied. Random variations do not depend on the case, but are specific to the value of the mean demand. Overall variance is the sum of the two effects. This means that K-factors change slightly with demand. This was seen in Figure 3. For demand levels above 100, the random component of K-factor has been a complication with little numerical significance. For smaller demands, it has improved estimates meaningfully.

The second revision of the spill model changed the spill values significantly. It was recognized that a flight's "truncating capacity" is not the seat count on the aircraft. A flight is not full at 100% load factor. It is full when reservations are no longer accepted. The limited number of reservations then translates through no-show behavior to a load at the gate. Optimal overbooking policies [Schlifer and Vardi] mean that the expected load is 5%-10% below the aircraft seat count. This 5%-10% is called "spoilage" in airline parlance. Spoilage averaged below 5% in the days of a single fare and reliable no-show behavior. In those times spoilage served solely to protect against excess overbooking, preventing denied boardings at the gate. With discount pricing and revenue management there is a second reason for spoilage. Revenue management holds some seats open for late-booking high-fare demand. This demand does not always materialize, but airlines are willing to take the chance, since revenues run three times the discount fares. When these seats are not called for, they add to spoilage. With discounting and revenue management, the average truncating capacity dropped toward 10% below seat counts.

These issues are illustrated in Figure 4. The "theoretical load distribution" has an impulse function representing the 100% load factor cases of flights being full. This is the old spill approach. The "actual load distribution" has a small hump of load outcomes in the 85%-95% load factor range that represents the loads at the gate for cases when discount reservations were no longer accepted. Simulations have shown that for spill calculations it is sufficient to represent this "hump" as an impulse function at the new truncating capacity, in this case at about 90% load factor.

The spill model was modified to use the new lower capacities. Needless to say this increased the estimates of spill.

Optimal spoilage levels involve an interaction of the overbooking and space-protecting aspects of revenue management. Simulation shows that the optimal spoilage levels for a given mix of fares and uncertainty rises with the square root of the aircraft capacity. That is for seat count R , spoilage s would be:

$$s \approx c \cdot \sqrt{R} \quad (6)$$

Studies showed that the factor c should be as low as 0.5 for a single fare case and could rise above 1.0 for cases with discounts similar to current US conditions. Large c values were appropriate when discount fares were low compared to full fares or when uncertainty in no-show rates was high.

Average spoilage for an airline implies the value for c . Spoilage should be deduced from the departing loads of flights that are closed to discount fares. When a flight is closed to discount fares, demand is being spilled. It is not appropriate to measure spoilage only from flights that are closed to high fare levels. These have low spoilage, but they are not representative. Nor are flights that are regularly full typical. They often record unusually low spoilage. This could be because no-show rates are more predictable, or it could be because stand-by demand tops up the loads. For most planning uses, it is appropriate to calibrate spoilage from a broad representation of closed flights and not from only from flights that are closed to full fare or closed frequently. While it is important to include spoilage in predictions of fill or spill, results are not overly sensitive to getting the exact spoilage value correct.

The concept of spoilage changes the spill formulas in a simple way. The capacity parameter C becomes the seat count less the spoilage:

$$C = R - s \quad (7)$$

5. REVENUES FOR SPILL

The spill model predicts spilled demand. The natural question is, what is the revenue for that spilled demand? The discussion of spoilage recognized that spill takes place by turning away discount demand as it requests a reservation. Revenue management systems' function is to spill discount demand and maintain space for higher fare demand. So the question of what revenue is spilled is either very complicated or completely simple. The complicated answer involves understanding what a revenue management system is trying to do on a detailed level, and how well it succeeds. The simple answer is that spill is at the local market discount fare. Discussion will try to motivate the simple answer.

The purpose of a revenue management is to spill discount fares when spill must occur at all. Most current revenue management systems group fares in to "buckets" and limit sales from

the lowest fare bucket. A typical flight leg is half local traffic, and the local traffic is usually well over half at discount fares. Local discount fares are lower than connecting discount fares. So most revenue management systems limit local discounts first.

Even the best revenue management systems do a poor job of spilling just discount when load factors are low and spill is small. However, when significant numbers of passengers need to be turned away, it is easier to deny mostly discount demand. Furthermore, spill applications value differences in spill. That means it is not the average fare turned away that counts, but the average fare of one last increment of spilled demand that counts. Simulations of leg-based revenue management systems suggest that when spill is not too small, 80% of it is turned away at the discount fare, and only 20% at an average mix of fares. This split is fairly consistent from modest levels of spill up to very high levels of spill and over a range of discount market shares and prices. The rule breaks down at high levels of spill, when all the discount demand has been denied and higher fares need to be refused. The practical conclusion is that spill revenues are just above the discount levels.

The most advanced revenue management systems try to do better. Origin-Destination based systems try to turn away demand from two-leg connecting discounts if both legs are likely to be spilling. The revenue lost per leg becomes only a share of the connecting discount fare. The value is well below the local discount fare. This line of reasoning means average spill is at revenues slightly below the local discount, not slightly above.

Overall, spill is at the local discount fare, or at a value within 10% of this number for planning cases. This is well within the uncertainty of estimates for other parts of a plan. For markets such as domestic US hub services, the value runs about 75% of the average yield allocated to a flight leg.

6. RECAPTURE OF SPILL

Recapture is the idea that spilled demand does not fail to take the trip. Some of it finds its way back on to other flights by the same airline. This is easy to visualize on a daily or weekly basis. Spill from the 9:00 flight will divert to seats on the 11:00 flight, and spill on the Tuesday departure can arrange to go on Wednesday. For a day or a week, spill modeling certainly needs to address the issue of recapture.

Recapture is less of an issue for fleet planning. In fleet planning, spill in August cannot be expected to use space in February, and spill to London does not board the flight to Miami. While some spill does find space on adjacent flights, the last incremental units of spill are left with fewer and fewer open alternatives. The broader or longer-run the case or the higher the spill values, the smaller the likelihood of practical recapture.

For the shorter-run, there is still a need for understanding recapture behavior. This has been studied with demand models that simulate passenger choices and preserve the second, third, and fourth choice departures for spilled passengers. It is important to preserve a list of

alternatives, since if a passenger has been spilled off his first choice, he is late booking. Other flights are likely to be full with primary demand or earlier recaptured demand. While a short list is important, preserving a very long list presents a problem. At some point customers give up and replan their trip around a different set of times or days. Nonetheless, the list-of-choices logic has been used in simulations covering a month of flights with day-of-week and time-of-day cycles. The results suggest the following simplification of recapture behavior: spilled demand for a city pair loads itself on flights as if it is seeking empty seats with little attention to schedule. After a first pass of primary demand and primary spill, the pool of spilled demand distributes itself at equal load factors on the remaining available space in the market. Available space is measured as the seats between the first-pass load and the truncating capacity C .

This result is a lot less certain than earlier statements about spill. Modest load factors and small spill will produce the more intuitive result that the more popular flights get most of the recapture. High demands produce the obvious answer that all available capacity is used, and the excess demand is lost entirely.

This understanding of recapture has an significant corollary. Extra seats on flights are not only useful for preventing spill from the flight, they also have value for accommodating spill from competitors flights or off other flights of the same airline. The reverse side of the "recapture" coin is this constructive use of extra capacity. The term suggested for this phenomenon is "refill."

Recapture means spill is less costly less than it seems. This means extra seats are less valuable. Refill means extra seats have increased value. The two parts of the recapture phenomenon do not exactly cancel out, but they can be of similar size. It is not correct to include one without the other.

In annual or fleet cases recapture is small, particularly for incremental changes. For monthly cases for a single flight leg, recapture can be important, but the phenomenon of refill cancels some of its value. Overall, recapture requires a great increase in complication. Unfortunately, is also is an area where current research has leaves a great deal of uncertainty. Many analyses choose to argue that recapture and refill are second-order effects and leave them out.

7. ERRORS IN ESTIMATION

Spill can be estimated, but how good is the estimate? Spill calculations require estimates of a number of parameters. The mean demand, K-factor, spoilage, average revenues, recapture, and refill all have uncertainties in their estimates. The way to test these estimates is to compare their effect on the value of an incremental seat on the aircraft. The value of a seat is the fill rate. This percentage will then be multiplied by the expected fare for spilled passengers to get the value for an extra seat. The table below develops an example with variations reflecting the separate uncertainties. Estimate of the uncertainty of individual parameters is from experience in spill applications.

Table 2: Errors in Spill Value for a Flight-Leg Month

<u>Parameter</u>	<u>Estimated Value</u>	<u>Estimate Uncertainty</u>	<u>Range of result (Seat Value)</u>
Capacity (base \$)	200	± 0	\$31
Demand	150	± 15	\$17-\$48
K-cyclic	0.30	± 0.05	\$26-\$36
spoilage factor "c"	0.85	± 0.15	\$29-\$33
Spill Fare	\$150	± \$25	\$26-\$36

Table 2 shows a value of \$31 for a typical case of a spill for a flight leg for a month. This represents using spill to help decide which aircraft type to assign to flight legs in a published schedule 3 months before the schedule will be flown. The \$31 is the value of an incremental seat using the estimated values for the list of parameters. The greatest uncertainties lie outside the spill model. Demand uncertainty is the dominant source of error. Uncertainty in the mean demand reflects not so much the forecast of industry demand three months ahead as the uncertainty of allocation for one particular flight leg month after month. Uncertainties in the fare represent both the difficulty of forecast for a single flight leg and the controversy about exactly which fare is spilled. Uncertainty in spoilage has only 10% of the effect of demand uncertainty, and doubt about the proper estimate for K-cyclic is under a quarter. For such a short-run study, recapture and refill values would be relevant. Uncertainties in these would equal demand effects.

For fleet planning, fill values are higher for the same demand factor, because the data for a fleet for a year has more variation from its average than a flight leg for a month. Although fill values are higher, the errors are lower. Averaging across an entire system reduces the uncertainty in K-cyclic and spill fare estimates, and recapture and refill are much smaller issues for annual and fleet spill.

8. ESTIMATING DEMAND

The spill model starts with an estimate of the unconstrained demand for a flight. Often, this estimate comes from historical loads. This is fine when load factors were low. An iterative process can establish what the demand should have been for spill to result in the observed load. However, when spill is an issue, load factors are already high. With high load factors, most flights are full and there is little information in the load distribution. It is very hard to determine what the underlying demand distribution was from the shape of the observed load curve. Another way to see this is shown in Figure 5. Implied demand factor is shown against observed load factor for a flight leg for a month. This is based on numerical inversion of the spill formula. Above 85% load factor, as little as a 0.5% point rise in observed load implies a huge increase in demand. To make matters worse, errors in the estimated spoilage are likely, particularly at high demands. Differing spoilage estimates will give large changes in implied demand. Used in reverse, the spill model does not work in practice at high spill. Numerically, the spill model is poor at "detruncation."

Two methods are used to get around this. Neither are particularly convenient. The simplest is to look at the leg in question at a lower load factor time, and scale the demand up in proportions typical for similar markets suffering less truncation. The second is to collect information from the revenue management system on day-by-day spilled demand and establish the monthly average. To set its levels, revenue management must forecast the unconstrained demand for each fare class for each flight leg. Unfortunately, these forecasts are often used but not recorded. When they are recorded, they are not always very good estimates. Forecasting within revenue management systems also suffers from diminished information when spill is high and past bookings have been capped. Finally, recapture and refill add passengers to observed loads, further complicating the issue. All these complaints aside, estimates from the revenue management system are often far and away the best available.

The overall conclusion on demand estimation is that the spill model is fine for predicting spill when demand is known, but not good at helping with the estimates of demand to begin with.

9. SUMMARY AND CONCLUSION

Spill estimates the demand in excess of capacity. The model uses a demand distribution and truncates it with a capacity line. The demand distribution is usually normal. For a normal distribution convenient formulas exist. Such modeling is broadly used within the airline industry. Revisions to the model recognize an increase in the variance of the demand distribution when demand levels are small, due to random variations adding to the usual cyclic changes in demand. Revisions also adjust for overbooking and revenue management behavior by truncating demand at a capacity somewhat below the physical seat count. The revenue for spilled demand is close to the local discount fare. Spilled demand can be recaptured, and the possibility of refilling with recapture adds value to extra seats. However, recapture is small for fleet planning cases and can often be ignored. The great frustration with spill modeling is that for all its effectiveness in estimating spill when the unconstrained demand is known, it can seldom be employed with confidence to unconstrain demand from observed load averages.

Overall, spill modeling has produced practical understandings that have found wide use in the airline industry. Future use may be compromised by rising load factors and a developing trend to use pricing to fill under-utilized capacity. As pricing manipulates demand away from its underlying distribution over flights, the spill model use will require further inventiveness and could become less practical.

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Figure 1: Fill Rate and Spill

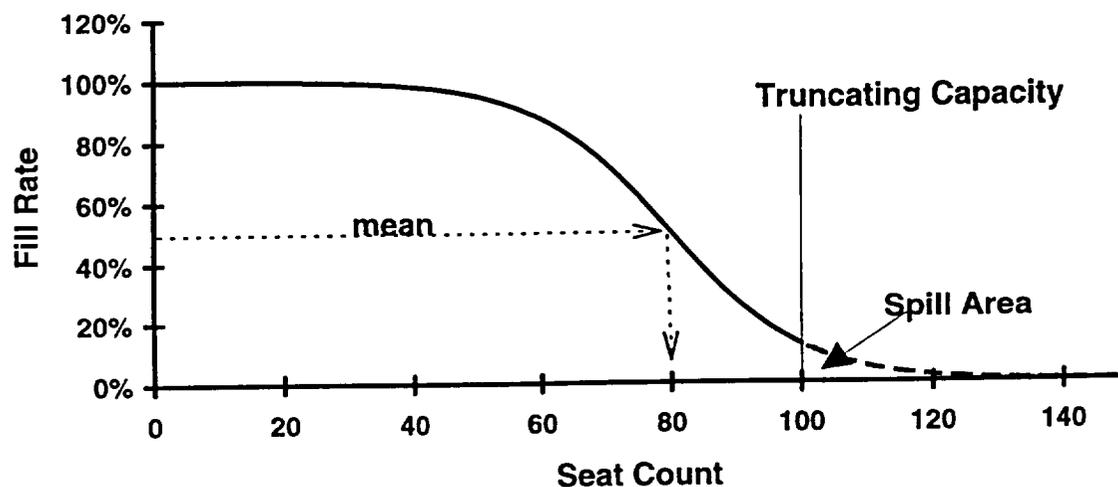


Figure 2: Normal and Gamma Shapes

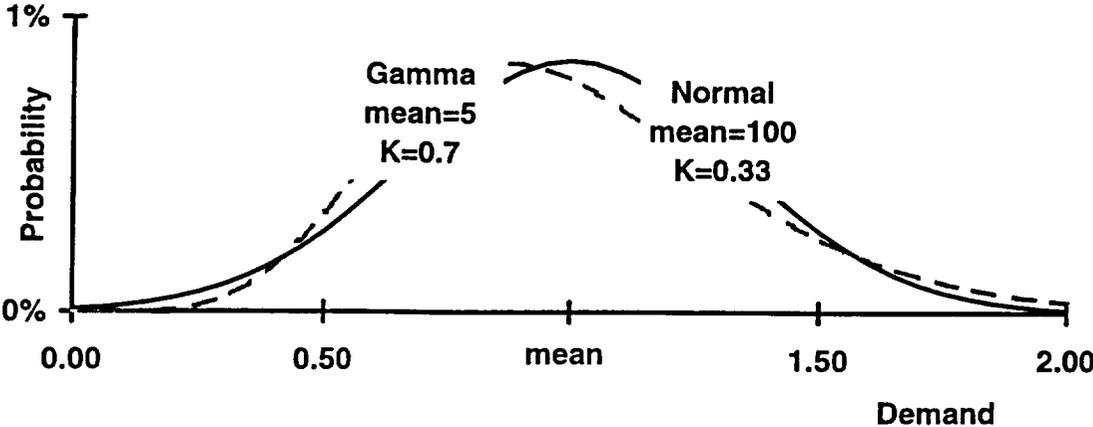


Figure 3: K-factor Rises for Smaller Demands

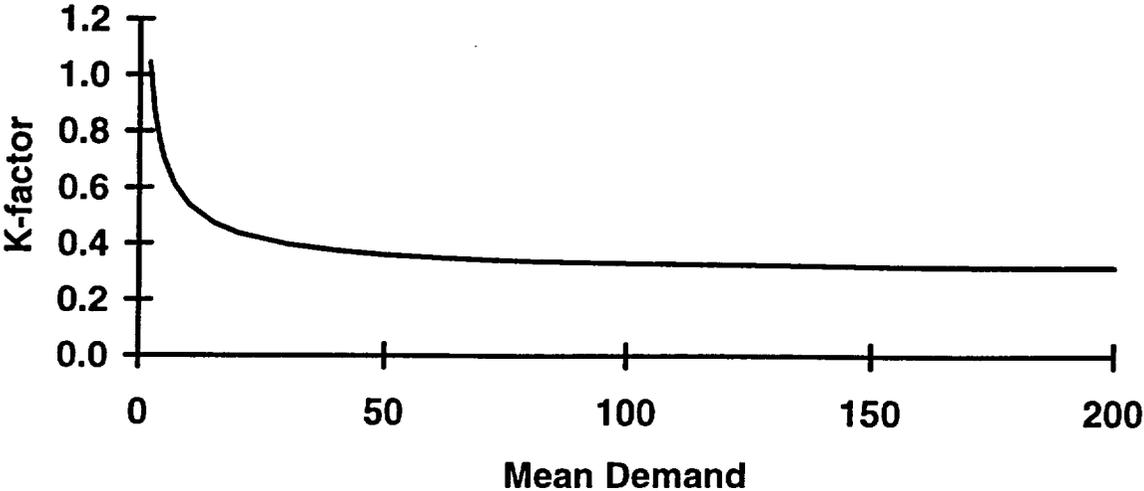


Figure 4: Loads: Theory and Practice

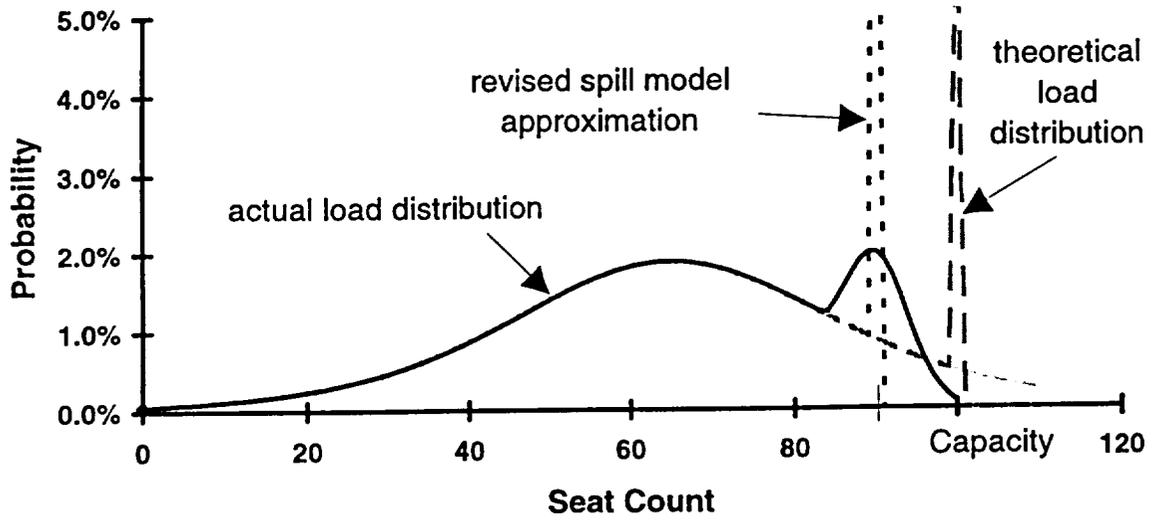
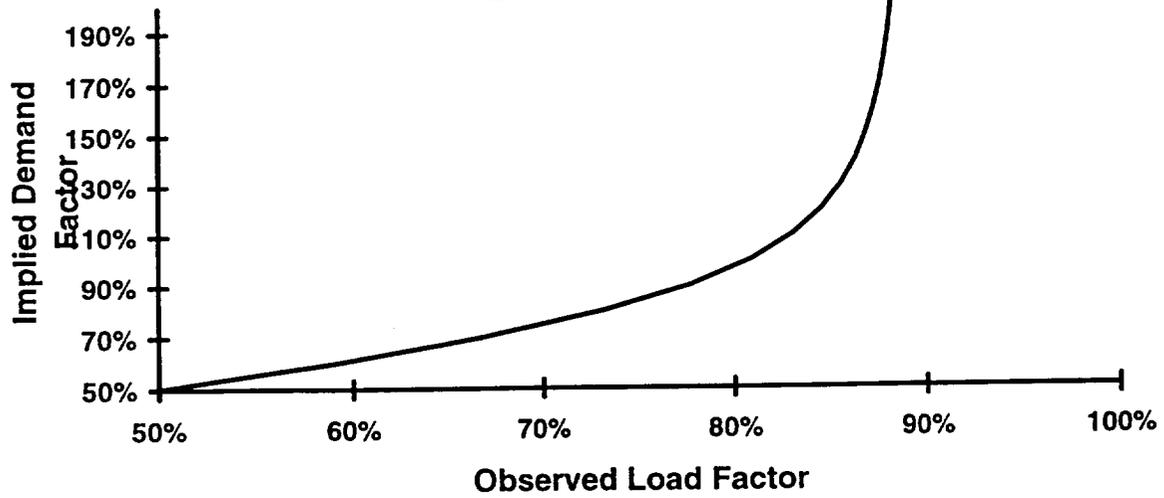


Figure 5: Implied Demand Skyrockets at High Load Factors



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Airline Spill Analysis – Beyond the Normal Demand

By

Michael Z.F. Li and Tae Hoon Oum

Abstract

Most research on airline passenger spill has assumed the normal distribution of the nominal demand. But, there are plenty of empirical evidences showing that the normal distribution does not fit very well in many occasions, especially for the demand for business and first class compartments. In this paper, we derive formulae for calculating the expected number of spilled passengers for a group of flights for the cases where the nominal demand is assumed to follow a normal, a logistic, a lognormal and a gamma distribution. The spills under the alternative distributional assumptions are compared numerically. Finally, the paper demonstrates that, for each of the four distributions, one can construct a generic observed load factor (OLF) table, which does not depend on aircraft seating capacity.

1. INTRODUCTION

Spill models predict average lost sales when demand exceeds flight capacity, and has been used by the airline industry since mid-1970s (see Schlifer and Vardi, 1976). The spill models provide critical information for selecting aircraft size to use for a particular market, how to assign an airline's existing aircraft fleet to various markets and schedules, and to determine type of aircraft for meeting future demands. They also form an integral part of dynamic pricing and yield management system. The idea behind a spill modelling is that demand for a group of flights can be represented by a probability distribution around a mean value. The group of flight can be defined according to the wishes of the analyst or the airline that wishes to use the results. For example, the group can involve one flight segment, a small group of segments served by single or multiple aircraft types or all the segments served by a single fleet type.

Airline passenger spill analysis has traditionally relied on the normal distribution assumption of the nominal demand. But, there are plenty of empirical evidences showing that the normal distribution in fact does not fit very well in many occasions, especially for the demand for business or first class compartment. In this paper, we derive formulae for calculating the expected number of spilled passengers for a group of flights when the nominal demand is assumed to follow a normal, a truncated normal, a logistic, or a gamma distribution. The spill rates under various distributional assumptions are compared numerically. Finally, the paper demonstrates that, for each of the four distributions, one can construct a generic observed load factor (OLF) table, which does not depend on seating capacity of the aircraft.

This paper is organized as follows. Section 2 develops the analytical foundation of the airline spill analysis by first establishing an important distribution-free identity relationship among the observed load factor, the nominal load factor and the spill. The main focus of this section is to extend the traditional wisdom of normality assumption of the nominal demand by deriving the spill calculation formulas for several other practically probability distribution functions, namely, logistic, log-normal, and Gamma distribution. Section 3 starts with the discussion of parameter conversions and the role of CV in the shape of the demand distributions. We will then present a few numerical comparisons on spill calculations under the four distributions discussed in Section 2. The last section is the conclusion.

2. ANALYTICAL FOUNDATION OF SPILL ANALYSIS

2.1 Definitions and Notation

Let X be the random demand for a flight, or a fare class; and C the seating capacity level under consideration. Since X is the true demand for the flight, X is frequently called as the *nominal demand* in order to distinguished it from the *observed demand* which is the number

of seats actually sold.¹ During the booking process, once the number of booking requests exceeds the capacity, the airline refuses any additional booking. These additional passengers rejected in reservation process are called *spilled passengers*. However, since the demand is random the airline can not be certain about the exact number of spilled passengers. Also, the truncation of random demand by capacity limitation makes difficult to examine true empirical distribution of the demand. On the other hand, for airline spill analysis and demand forecasting it is important for the airline to identify accurately the true (nominal) demand distribution from observable demand data.

Let us first introduce a few relevant concepts that will standardize our presentation.

Definition 1: Let X be the nominal demand for a flight with capacity of C .² Then

1. *Nominal load factor (NLF)* is defined as $E(X) / C$;
2. *Observed mean load* is the expected value of the nominal demand X truncated at the capacity level C , that is, $E(\min(X, C))$; and *the mean observed load factor (OLF)* is defined as $E(\min(X, C))/C$;
3. The *fill rate (FR)* for the p -th seat is defined as $P(X \geq p)$, that is, the probability that demand is equal to or greater than p ;
4. The *spilled passengers (SP)* is the number of passengers turned away because the flight is fully booked.³ Or mathematically speaking,

$$SP = E[(X - C) I_{(X > C)}], \quad (1)$$

where $I_{(X > C)}$ is the indicator function defined as $I_{(X > C)}(x) = 1$ if $x > C$ and 0 if $x < C$.

5. The *spill rate (SR)* is defined as the ratio of spilled passengers over the mean of the nominal demand, that is,

$$SR = SP / E(X) = E[(X - C) I_{(X > C)}] / E(X) \quad (2)$$

For a standard normal distribution $N(0,1)$, let $\phi(x)$ and $\Phi(x)$ be the corresponding probability density function and the cumulative probability distribution function respectively, that is,

$$\phi(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \quad \text{and} \quad \Phi(x) = \int_{-\infty}^x \phi(t) dt.$$

Before proceeding further, it is necessary for us to establish a simple but useful relationship between the nominal load factor (NLF), the observed load factor (OLF), the spill passengers (SP) in the following lemma.

Lemma 1: It is always true that $OLF = NLF - SP / C$.

¹ In this paper, we will use the flight demand and the nominal demand interchangeably.

² The capacity here is not necessarily the physical capacity of the flight. Nowadays, airlines tend to use the *effective capacity* for the spill analysis, see Swan (1992).

³ Sometimes, we also call the spilled passengers simply as the *spill*.

Proof: First note that the observed demand X_o is the nominal demand truncated at the capacity level C :

$$X_o = X I_{[X \leq C]} + C I_{[X > C]}.$$

Therefore, the expected load is given by,

$$\begin{aligned} E(X_o) &= \int_{-\infty}^C xf(x)dx + C \int_C^{\infty} f(x)dx \\ &= \mu_x - \int_C^{\infty} xf(x)dx + C \int_C^{\infty} f(x)dx = \mu_x - \int_C^{\infty} (x - C)f(x)dx \\ &= \mu_x - SP \end{aligned}$$

Therefore, we have that $OLF = (\mu_x - SP) / C = NLF - SP / C$, as required.

It follows immediately from the above lemma that $OLF = (1 - SR) \times NLF$, which is an universal relationship among OLF , NLF and the spill rate (SR).

2.2 Spill Formula for Some Common Distributions

In this subsection, we derive the basic spill formula for several commonly used distribution functions. As is well-known, the traditional spill analysis has mainly been focused on normal distribution, and occasionally Gamma distribution. On the other hand, empirical distributions for the observed demands are usually more diverse. Therefore, it is interesting and necessary to explore other types of probability distribution for the demand. According to Swan (1992), the demand for the first class cabin is usually neither a normal nor a Gamma distribution.

In this section, analytical formulae for the expected spill and the spill rate are to be derived for four alternative demand distributions.

(A) Normal Distribution

Let X follow a normal distribution with the mean μ and the variance σ^2 , or simply, $N(\mu, \sigma^2)$. The density function for X is:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \quad -\infty < x < \infty.$$

Then the expected number of spilled passengers is given by:⁴

⁴ This expression in (3), to our knowledge, was first appeared in Shlifer and Vardi (1975) in a different context. In a more focused paper on airline spill analysis, Swan (1983) derived both of these formulae.

$$\begin{aligned}
SP &= E[(X - C)I_{(X > C)}] = \int_C^{\infty} (x - C)f(x)dx \\
&= \sigma \int_b^{\infty} (t - b)\phi(t)dt = \sigma \int_b^{\infty} \frac{t}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt - \sigma b \int_b^{\infty} \phi(t)dt \\
&= \sigma \frac{1}{\sqrt{2\pi}} \left[-e^{-t^2/2} \right]_{t=b}^{\infty} - \sigma b(1 - \Phi(b)) = \sigma[\phi(b) - b(1 - \Phi(b))]
\end{aligned} \tag{3}$$

where $b = (C - \mu)/\sigma$, which is often known as the *buffer*. Consequently, the spill rate for the normal distribution becomes

$$SR = SP / \mu = CV \times [\phi(b) - b(1 - \Phi(b))], \tag{4}$$

where $CV = \sigma/\mu$ is the *coefficient of variation*, which is usually used to measure the variability of a probability distribution.

(B) Logistic Distribution

The logistic distribution has been frequently used in airline spill analysis. The popularity of a logistic distribution in spill analysis is mainly due to two reasons: (a) logistic distribution gives a reasonable approximation to normal distribution; and (b) a simple formula for spill calculation can be obtained from the logistic distribution. Also, the logistic approximation could be calibrated to fit nicely between the results of a normal distribution and a Gamma distribution in the relevant ranges of spill calculation (Swan, 1992). This subsection gives a closed-form expression for the spill formula when a general logistic distribution is used to model the nominal demand.

A random variable X is said to have a logistic distribution with parameters θ and β if it has the following probability density function:

$$f(x) = \frac{\exp\{(x - \theta) / \beta\}}{\beta[1 + \exp\{(x - \theta) / \beta\}]^2} \quad \text{for } -\infty < x < \infty, \tag{5}$$

where θ is the location parameter such that $-\infty < \theta < \infty$ and β is the scaling parameter such that $0 < \beta < \infty$. We will denote this distribution by $L(\theta, \beta)$. It is easy to check that a $L(\theta, \beta)$ distribution is symmetric around θ and also has a bell-shape look as a normal distribution. But we should bear in mind that the logistic density function has a relatively longer tails and is more peaked in the center than the normal density function.

The mean and the variance of a $L(\theta, \beta)$ distribution are given by:

$$E(X) = \theta \quad \text{and} \quad \text{Var}(X) = \beta^2 \pi^2/3$$

This implies that $\beta = \sqrt{3}\sigma_X/\pi$. Now note that

$$\begin{aligned}
SP &= E((X - C)I_{(X > C)}) = \int_C^{\infty} (x - C)f(x)dx \\
&= \int_C^{\infty} (x - C) \frac{e^{(x-\theta)/\beta}}{\beta(1 + e^{(x-\theta)/\beta})^2} dx \\
&= \int_{(C-\theta)/\beta}^{\infty} [\beta y + \theta - C] \frac{e^y}{(1 + e^y)^2} dy \quad (\text{by taking } y = (x - \theta) / \beta) \\
&= \beta \int_c^{\infty} (y - c) \frac{e^y}{(1 + e^y)^2} dy \quad (\text{by letting } c = (C - \theta) / \beta) \\
&= \beta \left[(y - c) \left(-\frac{1}{1 + e^y} \right) \right]_{y=c}^{y=\infty} + \beta \int_c^{\infty} \frac{dy}{1 + e^y} \\
&= 0 + \beta \int_c^{\infty} \frac{e^{-y}}{1 + e^{-y}} dy = \beta [-\ln(1 + e^{-y})]_{y=c}^{y=\infty} = \beta \ln(1 + e^{-c}),
\end{aligned}$$

i.e.,

$$SP = \beta \ln(1 + e^{-c}) = \beta \ln(1 + e^{-(C-\theta)/\beta}). \quad (6)$$

Consequently, the spill rate is

$$SR = SP / E(X) = (\beta / \theta) \ln(1 + e^{-(C-\theta)/\beta}). \quad (7)$$

To our knowledge, the above formula is new. Interestingly, there was an indirect application of logistic distribution in spill calculation due to the fact that it can be used as an approximation for the normal distribution. The original attempt was mainly done by Swan (1983). For the purpose of comparison, let us address this issue in more details.

Recall that, in the derivation of SP formula for the normal distribution, in (3) we have

$$SP = \sigma \int_b^{\infty} (t - b) \phi(t) dt \quad (8)$$

where $b = (C - \mu) / \sigma$ is the buffer, as defined above. Instead of using the exact normal distribution function and derive the spill formula, in equation (8) one can use the following logistic density function as an approximation of the normal density function $\phi(t)$:

$$f_w(t) = \frac{we^{wt}}{(1 + e^{wt})^2} \quad (9)$$

where $w = 1.7$. This leads to the following formula for SP:

$$\begin{aligned}
SP &= \sigma \int_b^{\infty} (t-b) \frac{we^{wt}}{(1+e^{wt})^2} dt \\
&= \sigma \left[(t-b) \left(-\frac{1}{1+e^{wt}} \right) \right]_{t=b}^{\infty} + \sigma \int_b^{\infty} \frac{1}{1+e^{wt}} dt \\
&= 0 + \frac{\sigma}{w} \int_{wb}^{\infty} \frac{1}{1+e^v} dv = \frac{\sigma}{w} \ln(1+e^{-wb})
\end{aligned}$$

Then the corresponding formula for the spill rate under this approximation becomes,

$$SR = \frac{\sigma}{w\mu} \ln(1+e^{-wb}) = \frac{CV}{1.7} \ln(1+e^{-1.7b}) \quad (10)$$

Equation (7) can be rewritten, in terms of the buffer b , as follows:

$$\begin{aligned}
SR &= (\beta/\theta) \ln(1+e^{-(c-\theta)\nu\beta}) \\
&= \frac{\sigma}{\mu \times \frac{\pi}{\sqrt{3}}} \ln(1+e^{-\frac{\pi}{\sqrt{3}} \frac{c-\mu}{\sigma}}) \approx \frac{CV}{1.8138} \ln(1+e^{-1.8138b})
\end{aligned} \quad (11)$$

This is different from the spill rate formula (10). The difference between (10) and (11) is caused mainly by the difference in distributional assumption of the nominal demand. In fact, according to Johnson et al (1995, p. 119), when $w = 1.7017456$ the logistic distribution in fact provides the best approximation to the standard normal distribution.

(C) *Log-normal Distribution*

Now consider that nominal demand, X , follows a log-normal distribution, implying that there exist some constants γ , δ and θ such that

$$U = \gamma + \delta \ln(X - \theta) \sim N(0, 1).$$

With this relationship, it can be shown that the probability density function of X is given by,

$$f(x) = \frac{\delta}{\sqrt{2\pi}(x-\theta)} e^{-(\gamma+\delta \ln(x-\theta))^2/2}, \quad x > \theta.$$

For our purpose, let $\theta = 0$. Then, it is straightforward to check that the r -th moment of X is given by

$$E(X^r) = \exp\{r\mu + (r\sigma)^2/2\}$$

where $\mu = -\gamma/\delta = E(\ln(X))$ and $\sigma^2 = 1/\delta^2 = \text{Var}(\ln(X))$. Consequently, the mean and the variance of the X are given by

$$E(X) = e^\mu e^{\frac{1}{2}\sigma^2} \quad \text{and} \quad \text{Var}(X) = e^{2\mu} e^{\sigma^2} (e^{\sigma^2} - 1).$$

With $\theta = 0$ and using the parameters μ and σ , the density function of the log-normal distribution can be rewritten as follows:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma x}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}, \quad \text{for } x > 0.$$

Let us now derive the formula for spilled passengers for a log-normal distribution:

$$\begin{aligned} SP &= E[(X - C)I_{(X > C)}] = \int_C^\infty (x - C)f(x)dx \\ &= \int_C^\infty \frac{x - C}{\sqrt{2\pi\sigma x}} e^{-\frac{1}{2}\left(\frac{\ln x - \mu}{\sigma}\right)^2} dx \\ &= \frac{1}{\sqrt{2\pi\sigma}} \int_C^\infty e^{-\frac{1}{2}\left(\frac{\ln x - \mu}{\sigma}\right)^2} dx - \frac{C}{\sqrt{2\pi\sigma}} \int_C^\infty e^{-\frac{1}{2}\left(\frac{\ln x - \mu}{\sigma}\right)^2} \frac{dx}{x} \\ &= \frac{1}{\sqrt{2\pi\sigma}} \int_c^\infty e^{-\frac{t^2}{2}} \sigma e^{\sigma + \mu} dt - \frac{C}{\sqrt{2\pi\sigma}} \int_c^\infty e^{-\frac{t^2}{2}} \sigma dt \quad (\text{by taking } t = \frac{\ln x - \mu}{\sigma}) \\ &= \frac{1}{\sqrt{2\pi}} \int_c^\infty e^{-\frac{t^2 - 2\sigma - 2\mu}{2}} dt - C(1 - \Phi(c)) = \frac{e^{\mu + \sigma^2/2}}{\sqrt{2\pi}} \int_c^\infty e^{-\frac{(t - \sigma)^2}{2}} dt - C(1 - \Phi(c)) \\ &= e^{\mu + \sigma^2/2} (1 - \Phi(c - \sigma)) - C(1 - \Phi(c)) \end{aligned}$$

where $c = (\ln C - \mu)/\sigma$. Consequently, the spill rate will given by,

$$SR = \frac{SP}{E(X)} = (1 - \Phi(c - \sigma)) - \frac{C}{e^{\mu + \sigma^2/2}} (1 - \Phi(c)). \quad (13)$$

(D) Gamma Distribution

According to Swan (1983), there are three main reasons why Gamma distribution is attractive for modeling the nominal demand. First, the guarantee of non-negative demand is more realistic than a normal distribution. Second, Gamma distribution appears to be closer to the shape of the observed load distribution, especially for some flights on high demand days since they generally have fatter positive tails than the normal distributions. Finally, the Bernoulli trial component variation is a Gamma distribution.

But interestingly, there has not been any formal development of the spill analysis using Gamma distribution. Recall that the probability density function of a standard two-parameter Gamma distribution is

$$f(x) = \frac{x^{\alpha-1} e^{-x/\beta}}{\beta^\alpha \Gamma(\alpha)}, \quad \text{for } x \geq 0 \text{ with } \Gamma(\alpha) = \int_0^\infty x^{\alpha-1} e^{-x} dx.$$

In this two-parameter Gamma distribution, α is the shape parameter and β is the scale parameter. It is easy to show that the moment generating function of the Gamma distribution is given by $m(t) = E(e^{tX}) = (1 - \beta t)^{-\alpha}$. And the corresponding mean and variance are $E(X) = \alpha\beta$ and $Var(X) = \alpha\beta^2$. Hence $CV = 1/\sqrt{\alpha}$. Now let us derive the spilled passengers:

$$\begin{aligned} SP &= E((X - C)I_{(X > C)}) = \int_C^\infty (x - C)f(x)dx \\ &= \int_C^\infty (x - C) \frac{x^{\alpha-1} e^{-x/\beta}}{\beta^\alpha \Gamma(\alpha)} dx = \int_C^\infty \frac{x^\alpha e^{-x/\beta}}{\beta^\alpha \Gamma(\alpha)} dx - C \int_C^\infty \frac{x^{\alpha-1} e^{-x/\beta}}{\beta^\alpha \Gamma(\alpha)} dx \\ &= \beta\alpha[1 - G(C, \alpha + 1, \beta)] - C[1 - G(C, \alpha, \beta)], \end{aligned}$$

where $G(x, \alpha, \beta)$ is the cumulative probability function of the Gamma distribution with the parameters (α, β) :

$$G(x, \alpha, \beta) = \int_0^x \frac{t^{\alpha-1} e^{-t/\beta}}{\beta^\alpha \Gamma(\alpha)} dt.$$

Therefore, the spill rate is given by,

$$SR = [1 - G(C, \alpha + 1, \beta)] - \frac{C}{\alpha\beta}[1 - G(C, \alpha, \beta)].$$

Since exponential distribution is a special case of Gamma distribution with $\alpha = 1$, it is each to check that the spill rate under an exponential distribution is given by $SR = e^{-C/\beta}$. But in practice, the exponential distribution is rarely used to model the demand.

It is worth noting that the spill calculation under a general Gamma distribution is far more numerically demanding than the other distributions, and direct uses of CV and the buffer b in the spill calculation are possible, but as natural as under the other distributions.

3. COMPARING SPILL VALUES

3.1 Conversion of Distributional Parameters

From the discussions in the previous section, it is clear that there is no closed-form solution for the spill calculation except the case of assuming a logistic distribution of the nominal demand. In the initial stage of spill analysis and application in the 1970s, logistic

approximation to the normal distribution was a natural and convenient choice because of its simplicity. Direct application of the normal or Gamma distribution would have involved substantial amount of additional coding and computational requirements. Dramatic changes have occurred in spill analysis as the spreadsheet software has become much sophisticated since the early 1990s. The purpose of this section is to use MS Excel to perform a few numerical calculations and comparisons for the spill analysis.

Over the years, practitioners in the airline industry have been calculating the spill or spill rate by directly applying the coefficient of variation (CV) and the expected demand $E(X)$ (i.e., μ_X). Table 1 summarizes these parameters of the alternative distributions discussed in this paper.

Table 1: Parameterizing Demand Distributions by Using CV and μ_X

Demand Distribution	Location/Shape Parameter	Scale Parameter	Spill Formula
Normal	$\mu = \mu_X$	$\sigma = CV \times \mu_X$	$\sigma[\phi(b) - b(1 - \Phi(b))], b = (C - \mu_X) / \sigma_X$
Logistic	$\theta = \mu_X$	$\beta = \frac{CV \times \mu_X}{\pi / \sqrt{3}}$	$\beta \ln(1 + e^{-(C-\theta)/\beta})$
Log-normal	$\mu = \ln \frac{\mu_X}{\sqrt{1 + CV^2}}$	$\sigma = \sqrt{\ln(1 + CV^2)}$	$\mu_X(1 - \Phi(c - \sigma)) - C(1 - \Phi(c)), c = \frac{\ln C - \mu}{\sigma}$
Gamma	$\alpha = \frac{1}{CV^2}$	$\beta = CV^2 \times \mu_X$	$\mu_X[1 - G(C, \alpha + 1, \beta)] - C[1 - G(C, \alpha, \beta)]$

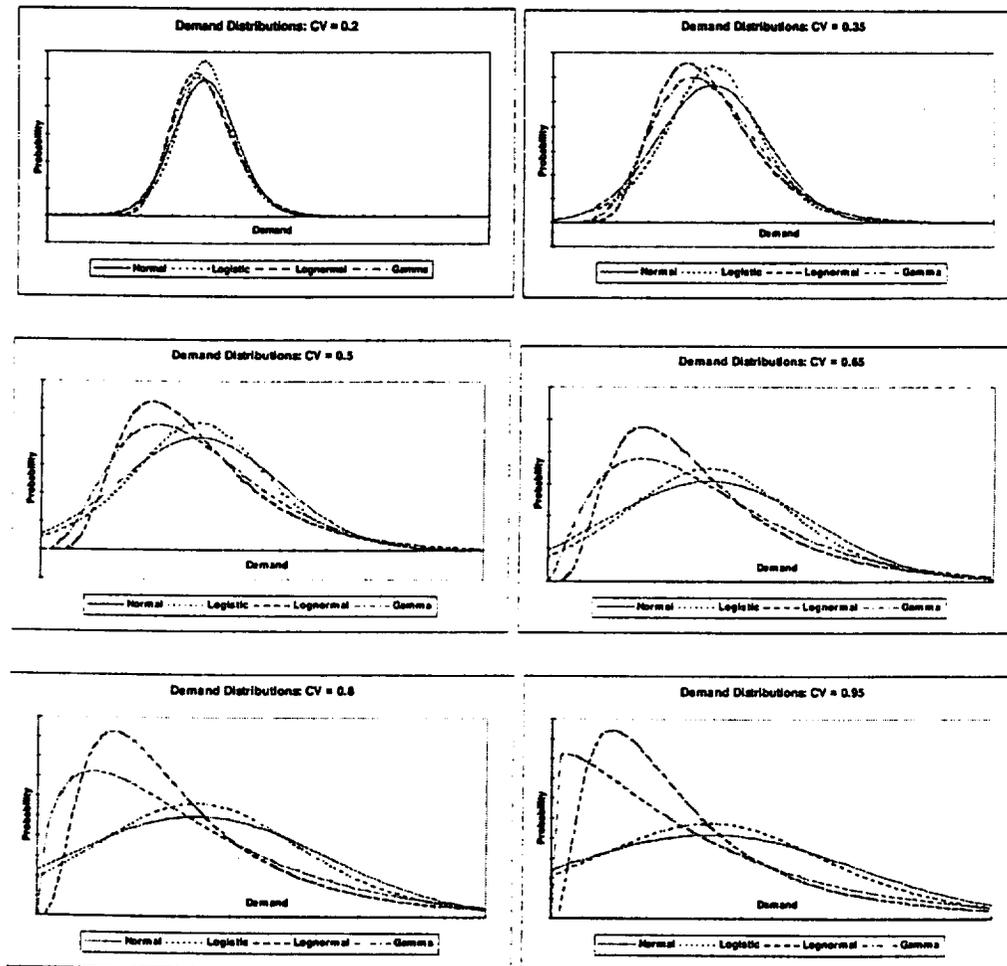
3.2 The Shape of Demand Distribution and the Value of CV

One of the important tasks in airline spill analysis is to accurately model the demand distribution. As pointed out earlier, Swan (1992) indicates that the normal distribution does not fit all situations. One of key issues is that the shape of the demand distribution is skewed to left for small cabins, implying a relatively large value of CV. Figure 1 below graphically illustrates this point, where all of the four distributions are assumed to have same values for the mean and CV.

One can make a few general observations from these figures. First, for small values of CV, all of the three non-normal distributions are close to a normal distribution, implying that there may not be any big difference in spill calculations under the four distributional assumptions. Second, a normal distribution becomes increasingly inappropriate to model the nominal demand as the value of CV increases. The spill calculated by assuming a normal distribution (or its logistic approximation, not shown in the figure) will clearly *over-estimate* the true spill when the value of CV is large. Third, the difference in spill between a log-normal distribution and a Gamma distribution will be surprisingly small for a large CV. Fourth, as the value of CV becomes larger, the Gamma distribution is getting close to the shape of an exponential distribution, which is usually not a good shape for demand. On the

other hand, the lognormal distribution behaves much more “robust” for the lower portion of the demand. Finally, for large values of CV , neither a normal nor a logistic distribution appears to be appropriate to model nominal demand because these distributions have relatively high probability of taking a negative demand while a negative value is impossible under a lognormal or a Gamma distribution.

Figure 1: The Shape of Demand Distribution and the CV



3.3 Numerical Comparisons of Spills Values

In this section, the spill values computed using the formulae derived for the four alternative distributions are compared numerically. For each of the four distributions, we calculate the spill for three different capacity levels, namely, $C = 300$ (large capacity), 150 (medium capacity) and 30 (small capacity), and three values of the CV: 0.2, 0.5 and 0.8.

Tables 2, 3, and 4, reports spill values for capacity level 300, 150 and 30 seats per aircraft, respectively. Each of these tables are arranged so as to make it easy to compare spill values for the four alternative distributions (A = Normal distribution; B = Logistic distribution; C = Log-normal distribution; D = Gamma distribution) at different levels of mean and coefficient of variation (CV) of the nominal demand.

Table 2: Spill Table – Capacity = 300

μ_x	CV = 0.2				CV = 0.5				CV = 0.8			
	A	B	C	D	A	B	C	D	A	B	C	D
220	0.6	0.9	1.3	1.0	15.0	14.4	18.4	18.2	37.3	35.3	38.0	41.2
230	1.3	1.6	2.2	1.9	19.1	18.2	21.9	22.0	43.7	41.2	42.7	46.6
240	2.4	2.6	3.4	3.1	23.7	22.4	25.8	26.2	50.3	47.6	47.8	52.3
250	4.2	4.2	5.2	4.9	28.8	27.2	30.0	30.8	57.3	54.2	53.0	58.2
260	6.6	6.3	7.6	7.3	34.3	32.4	34.6	35.7	64.5	61.2	58.5	64.4
270	9.8	9.3	10.6	10.4	40.2	38.1	39.5	41.0	72.0	68.5	64.2	70.7
280	13.8	13.0	14.2	14.2	46.4	44.1	44.7	46.6	79.7	76.0	70.1	77.2
290	18.5	17.6	18.6	18.7	53.0	50.6	50.2	52.5	87.6	83.8	76.2	83.9
300	23.9	22.9	23.7	23.9	59.8	57.3	56.0	58.6	95.7	91.7	82.5	90.8
310	30.1	29.1	29.4	29.7	67.0	64.4	62.1	65.0	104.0	99.9	88.9	97.9
320	36.8	35.9	35.7	36.2	74.3	71.7	68.4	71.7	112.4	108.2	95.6	105.1
330	44.0	43.2	42.7	43.2	81.9	79.3	75.0	78.6	121.0	116.7	102.4	112.4

Note: A = Normal; B = Logistic; C = Lognormal; D = Gamma.

Table 3: Spill Table – Capacity = 150

μ_x	CV = 0.2				CV = 0.5				CV = 0.8			
	A	B	C	D	A	B	C	D	A	B	C	D
115	0.6	0.8	1.1	0.9	9.6	9.1	11.0	11.0	21.8	20.6	21.4	23.3
120	1.2	1.3	1.7	1.6	11.9	11.2	12.9	13.1	25.2	23.8	23.9	26.2
125	2.1	2.1	2.6	2.5	14.4	13.6	15.0	15.4	28.6	27.1	26.5	29.1
130	3.3	3.2	3.8	3.7	17.1	16.2	17.3	17.9	32.3	30.6	29.2	32.2
135	4.9	4.6	5.3	5.2	20.1	19.0	19.8	20.5	36.0	34.2	32.1	35.3
140	6.9	6.5	7.1	7.1	23.2	22.1	22.4	23.3	39.9	38.0	35.0	38.6
145	9.2	8.8	9.3	9.3	26.5	25.3	25.1	26.2	43.8	41.9	38.1	42.0
150	12.0	11.5	11.8	11.9	29.9	28.7	28.0	29.3	47.9	45.9	41.2	45.4
155	15.0	14.5	14.7	14.9	33.5	32.2	31.0	32.5	52.0	49.9	44.5	48.9
160	18.4	17.9	17.9	18.1	37.2	35.9	34.2	35.8	56.2	54.1	47.8	52.5
165	22.0	21.6	21.3	21.6	41.0	39.6	37.5	39.3	60.5	58.3	51.2	56.2
170	25.8	25.5	25.0	25.3	44.8	43.5	40.9	42.8	64.8	62.6	54.7	59.9

Table 4: Spill Table – Capacity = 30

μ_x	CV = 0.2				CV = 0.5				CV = 0.8			
	A	B	C	D	A	B	C	D	A	B	C	D
20	0.0	0.0	0.0	0.0	0.8	0.8	1.2	1.2	2.6	2.5	2.9	3.1
22	0.1	0.1	0.1	0.1	1.5	1.4	1.8	1.8	3.7	3.5	3.8	4.1
24	0.2	0.3	0.3	0.3	2.4	2.2	2.6	2.6	5.0	4.8	4.8	5.2
26	0.7	0.6	0.8	0.7	3.4	3.2	3.5	3.6	6.5	6.1	5.8	6.4
28	1.4	1.3	1.4	1.4	4.6	4.4	4.5	4.7	8.0	7.6	7.0	7.7
30	2.4	2.3	2.4	2.4	6.0	5.7	5.6	5.9	9.6	9.2	8.2	9.1
32	3.7	3.6	3.6	3.6	7.4	7.2	6.8	7.2	11.2	10.8	9.6	10.5
34	5.2	5.1	5.0	5.1	9.0	8.7	8.2	8.6	13.0	12.5	10.9	12.0
36	6.8	6.8	6.6	6.7	10.6	10.3	9.6	10.0	14.7	14.3	12.4	13.5
38	8.6	8.6	8.4	8.4	12.2	12.0	11.1	11.6	16.5	16.1	13.8	15.1
40	10.4	10.4	10.2	10.3	14.0	13.7	12.7	13.2	18.4	17.9	15.4	16.7
42	12.3	12.3	12.1	12.2	15.7	15.5	14.3	14.8	20.3	19.8	17.0	18.3

Note: A = Normal; B = Logistic; C = Lognormal; D = Gamma

From the above three tables, it is possible to make the following general observations:

- It is clear that the differences in spills among the four alternative distributions are quite small when $CV = 0.2$. This indicates that distributional assumption does not play a significant role in spill calculation when the demand is not very volatile, i.e. small CV value. This observation is consistent with the fact that, for small CV, all of the three non-normal distributions are close to a normal distribution.
- On the other hand, the differences in spill values between a normal distribution and a log-normal distribution are quite large for all three capacity levels, and increases with the value of CV. Therefore, the choice of a demand distribution becomes a far more serious issue when the demand is quite volatile. Furthermore, the capacity level has virtually no role to play when deciding which distribution should be used to model the demand. This is contrary to the findings of other studies on first class or business class spill analysis.

At this juncture, it is important to reiterate that whenever the spill model is used, the decision variable usually is not the spilled demand volume itself. It is usually the difference between the spill volumes for two competing cases. Consider the decision whether to assign a 130 (C_1) or a 150 (C_2) seat aircraft to a flight leg. The relevant question is, how many extra passengers will the extra seats accommodate, and whether or not the extra revenue would cover the extra cost of using a larger aircraft? The answer involves evaluating the difference in spill between the two cases. For a single incremental seat, this is the *fill rate* for the flight. For 5 incremental seats, it is simplest to take the difference of the two spill calculations, which is summarized in Table 5.

Table 5: Difference in Spills Between $C_1 = 130$ and $C_2 = 150$

μ_x	CV = 0.2				CV = 0.5				CV = 0.8			
	A	B	C	D	A	B	C	D	A	B	C	D
115	2.9	2.6	2.9	2.9	6.7	6.3	5.2	5.7	7.9	7.6	5.3	6.0
120	4.2	3.8	3.9	4.0	7.4	7.1	5.8	6.3	8.4	8.1	5.7	6.4
125	5.6	5.2	5.1	5.3	8.1	7.9	6.4	6.9	8.8	8.7	6.1	6.8
130	7.1	6.8	6.5	6.7	8.8	8.6	7.0	7.5	9.2	9.1	6.5	7.2
135	8.6	8.4	7.9	8.1	9.4	9.3	7.6	8.1	9.6	9.6	6.9	7.5
140	10.0	10.0	9.3	9.5	10.0	10.0	8.2	8.7	10.0	10.0	7.3	7.9
145	11.3	11.5	10.6	10.9	10.5	10.6	8.7	9.2	10.3	10.4	7.6	8.2
150	12.6	12.9	12.0	12.1	11.1	11.2	9.3	9.8	10.7	10.8	8.0	8.5
155	13.7	14.0	13.2	13.3	11.5	11.7	9.8	10.3	11.0	11.1	8.4	8.8
160	14.6	15.0	14.3	14.4	12.0	12.2	10.4	10.7	11.2	11.4	8.7	9.1
165	15.4	15.9	15.3	15.3	12.4	12.7	10.9	11.2	11.5	11.7	9.1	9.4
170	16.2	16.6	16.1	16.1	12.8	13.1	11.4	11.6	11.7	12.0	9.4	9.7

Note: A = Normal; B = Logistic; C = Lognormal; D = Gamma

Table 5, together with Tables 2, 3 and 4, suggests that compared with the log-normal and Gamma distributions, use of a normal distribution will not only over-estimate the spill at each capacity level, but also over-estimate the difference in spill when used to evaluate two alternative capacity levels. This over-estimation becomes increasingly serious as CV increases.

3.4 Generic OLF Table

For practical reasons, it is often important to have information on the observed load factors (OLF) associated with spill calculations. Before dealing with the numerical issues related to OLF, let us first establish the following surprising result.

Lemma 2: If the demand follows a normal, a logistic, a log-normal or a Gamma distribution, then the observed load factor (OLF) depends only on the nominal load factor (NLF) and the value of coefficient of variation (CV) of the distribution.

Proof: By Lemma 1, we know that $OLF = (1 - SR) \times NLF$. Therefore, to prove the lemma, it suffices to show that the spill rate (SR) under each of the four distributions can be expressed in terms of $NLF (= \mu_x / C)$ and CV . This is summarized in Table 6.

Table 6: Representation of Spill Rate by CV and NLF

Demand Distribution	Spill Rate Formula
Normal	$CV \times [\phi(b) - b(1 - \Phi(b))], b = (\frac{1}{NLF} - 1) / CV$
Logistic	$\frac{\pi}{\sqrt{3}} \frac{1}{CV} \ln[1 + e^{-\frac{\pi}{\sqrt{3}CV}(\frac{1}{NLF}-1)}]$
Log-normal	$(1 - \Phi(c - \sigma)) - \frac{1}{NLF} (1 - \Phi(c)), c = \frac{\ln \frac{\sqrt{1+CV^2}}{NLF}}{\sqrt{\ln(1+CV^2)}}, \sigma = \sqrt{\ln(1+CV^2)}$
Gamma	$[1 - G(\frac{1}{CV^2 \times NLF}, \alpha + 1, 1)] - \frac{1}{NLF} [1 - G(\frac{1}{CV^2 \times NLF}, \alpha, 1)]$

It is clear from Table 6 that the spill rate under each of the four distributions is a function of CV and NLF, as required.

An important consequence of this result is that it is possible to generate a *generic OLF Table*, which is not related to the capacity level. Table 7 below is such a generic OLF table. This kind of table is of great importance to practitioners in airline industry since only the value of OLF is observable.

Table 7: A Generic OLF Table

NLF	CV = 0.2				CV = 0.5				CV = 0.8			
	A	B	C	D	A	B	C	D	A	B	C	D
0.667	0.666	0.666	0.665	0.666	0.639	0.639	0.626	0.628	0.580	0.585	0.569	0.563
0.733	0.731	0.730	0.729	0.730	0.683	0.685	0.672	0.673	0.609	0.616	0.607	0.596
0.800	0.792	0.791	0.789	0.790	0.721	0.725	0.714	0.713	0.632	0.641	0.641	0.626
0.867	0.845	0.846	0.841	0.842	0.752	0.759	0.751	0.748	0.652	0.663	0.672	0.652
0.933	0.887	0.890	0.886	0.886	0.779	0.786	0.784	0.778	0.668	0.680	0.700	0.676
1.000	0.920	0.924	0.921	0.920	0.801	0.809	0.813	0.805	0.681	0.694	0.725	0.697
1.067	0.944	0.947	0.948	0.946	0.819	0.828	0.839	0.828	0.692	0.706	0.748	0.716
1.133	0.961	0.963	0.966	0.964	0.834	0.843	0.861	0.848	0.701	0.716	0.769	0.734
1.200	0.973	0.974	0.979	0.977	0.847	0.856	0.880	0.865	0.709	0.724	0.788	0.750
1.267	0.981	0.981	0.987	0.985	0.859	0.866	0.896	0.880	0.715	0.730	0.805	0.764
1.333	0.987	0.986	0.993	0.991	0.868	0.875	0.911	0.894	0.721	0.736	0.821	0.777
1.400	0.990	0.989	0.996	0.994	0.876	0.883	0.923	0.905	0.725	0.740	0.835	0.789

Note: A = Normal; B = Logistic; C = Lognormal; D = Gamma

This implies that one can quickly obtain value of the unobservable NLF from a generic OLF table if the distributional property of the demand is known to be one of the four distributions treated in this paper. With the information on the values of OLF and NLF , one can easily get the value of spill rate (SR) by using Lemma 1.

4. SUMMARY AND CONCLUSIONS

In this paper, we re-examined airline spill problem and went beyond the traditional assumption of normal demand distribution. We first established a distribution-free multiplicative relationship between the observed load factor (OLF), the nominal load factor (NLF), and the spill rate (SR). In addition to deriving the spill formula for the normal distribution again, new spill formulae were derived under a logistic, a lognormal, and a Gamma distribution. Furthermore, each of the four spill formulae is rewritten as a function of the mean demand and the coefficient of variation (CV), which are the common inputs used to calculate the spill in practice.

In our numerical example, the spills under three different levels of CV are calculated at three different capacity levels for each of the four distributions. It is found that for relatively small value of CV , there is no significant difference in the value of the spills across the four alternative distributions. As the demand become less stable, or equivalently, more volatile, the use of a normal distribution becomes problematic because of the increasing probability that the demand will assume a negative value. The numerical examples in fact show that the normal demand will not only over-estimate the spill at a given capacity level, but also over-estimate the difference in spill when two capacity levels are compared.

This paper also found the possibility of using a generic OLF Table for each of the four distributions because the expression for OLF is not directly related to the capacity. This table can be very useful to practitioners in spill analysis as it allows to infer the value of the nominal load factor from the OLF .

The main goal of this paper is to address some technical issues in airline spill analysis, especially in deriving the spill formulas. There are still a few areas that need further research. First, the estimation issue is non-trivial because of the fact that the observed demand was truncated at the capacity. Second, it will be quite interesting to study the implication of yield management system on the spill and vice versa. It is well known that modern yield management model typically uses the nested booking policy, implying that many low fare classes were *closed* before the flight departure time. Whenever a class is closed, there will be spill. It is not clear yet how to integrate these two. Finally, it is important that the demand based on real booking data need to be characterized empirically so that some useful guidelines for implementations can be set.

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An Airline Dynamic Multiple-Fare Overbooking Strategy Model

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1.INTRODUCTION

It is to standard for practice airline companies to allow passengers to cancel reservations booked in advance without penalty. In these circumstances, the likelihood is high that even with a given flight booked solid, seats would remain empty at take-off because of cancellations or passenger no-shows. In order to reduce the number of empty seats, airline companies resort to overbooking. Through carefully controlled overbooking, the airline companies can reduce the number of empty seats and at the same time serve the public interest by accommodating more passengers.

A number of conventional airline overbooking models have been developed in the past several decades. Various techniques have been attempted, yielding different degrees of success in their experiments. These include recognition approaches, such as a single overbooking level of single fare model developed by Beckmann (1958), Thompson (1961), Rothstein and Stone (1967), Rothstein (1971), Shlifer and Vardi (1975), Gerbracht (1979), Bodily and Pfeifer (1992); a comprehensive non-nested seat allocation and overbooking model developed by Chatwin (1993); a comprehensive nested seat allocation and overbooking model by Belobaba (1987).

2. A DYNAMIC MULTIPLE-FARE OVERBOOKING MODEL

The model of this paper contains a more comprehensive and exact treatment of the airline reservation's process than any of the foregoing. A discrete time approach is used and the reservation's procedure is viewed as Multiple-stages. With the aid of non-linear programming, solutions to the overbooking problem are obtained that maximize expected gain (passenger revenue minus costs of passengers denied boarding). The operating characteristics considered are the probability of cancellations, no-shows and denied boarding, and constructs multiple-fare penalty cost function that addresses the practical airline companies' operations under denied boarding situations. The model also considers the competition of different fare classes with each other in zero stage. Then overbooking process can include the operation of variable bookings of multiple-fare class. It better addresses the practical airline companies' operations under overbooking situations.

The model relates to a fixed nonstop flight and class of multiple-fare service. The system changes state from time to time according to a request arrival before departure at a reservation system. As above phenomena to be described, we construct the following model:

$$\max \sum_{i=1}^K \sum_{j=0}^{O_i^n} f_i^n(j) \cdot f_i \cdot \min[j, (B_{acc,i}^n + PL_{avsur,i}^n)] \quad (1)$$

$$- \sum_{i=1}^K \sum_{j=(PL_{avsur,i}^n + B_{acc,i}^n)+1}^{O_i^n} f_i^n(j) \cdot OSC_i(j - (B_{acc,i}^n + PL_{avsur,i}^n))$$

subject to $OV_i^n \geq 0$

$$BL^n = \sum_{i=1}^K OV_i^n$$

Where:

O_i^n : integer number of overbooking level on fare class i when decision period n ,
 $n = 0, 1, 2, \dots, N$.

BL^n : the integer number of booking level when decision period n .

$f_i^n(j)$: the cumulate probabilities of the number j of survival reserving
passengers on fare class i when decision period n , $j = 0, 1, 2, \dots$;
 $i = 1, 2, 3, \dots, K$

f_i : the fare class, $f_1 > f_2 > \dots > f_K$: $i = 1, 2, 3, \dots, K$

$B_{acc,i}^n$: in the constrain of booking capacity , the total booking passengers
who are accepted on board in decision period zero on fare class i
when decision period n . It is constructed as

$$\min \left\{ B_i^n, BC - \min \left[\sum_{l=0}^{i-1} (B_l^n + PL_{avsur,l}^n), BC \right] \right\}$$

$PL_{avsur,i}^n$: protection level considered average survival (the average of cancellation
probability and no-shows probability on fare class i when decision
period n).

$OSC_i(\bullet)$: oversales cost function on fare class i .

BL^n : is the overbooking limit when decision period n .

In (1), there are two conditions,: (a) oversales condition, and (b) spoilage condition,formulated as

$$(a) \sum_{i=1}^K \sum_{j=(PL_{avsur,i}^n + B_{acc,i}^n)+1}^{OV_i^n} f_i^n(j) \cdot f_i \cdot [B_{acc,i}^n + PL_{avsur,i}^n] , \text{for } j \geq (PL_{avsur,i}^n + B_{acc,i}^n + 1),$$

$$- \sum_{i=1}^K \sum_{j=(PL_{avsur,i}^n + B_{acc,i}^n)+1}^{OV_i^n} f_i^n(j) \cdot OSC_i(j - (B_{acc,i}^n + PL_{avsur,i}^n))$$

$$(b) \sum_{i=1}^K \sum_{j=0}^{(PL_{avsur,i}^n + B_{acc,i}^n)} f_i^n(j) \cdot f_i \cdot j \quad , \quad \text{for } j < (PL_{avsur,i}^n + B_{acc,i}^n + 1)$$

A useful extension of the analysis in the previous section is to consider the parameters $OSC_i(\bullet)$ (oversales cost function for class i) and $f_j^n(\bullet)$ (the probabilities of the number j of survival booking passengers on fare class i when decision period n).

(a) Oversales cost function on fare class i ; $OSC_i(\bullet)$

The function $OSC_i(\bullet)$ can be expressed in terms of single Oversales cost OSC , which are often assumed(Beckmann (1958), Thompson (1961), Rothstein and Stone (1967), Rothstein (1971), Shlifer and Vardi (1975), Gerbracht (1979), Bodily and Pfeifer (1992)). Rearranging and rewriting (1) gives

$$\max \sum_{i=1}^K \sum_{j=0}^{OV_i^n} f_i^n(j) \cdot f_i \cdot \min[j, (B_{acc,i}^n + PL_{avsur,i}^n)] \quad (2)$$

$$- \sum_{i=1}^K \sum_{j=(PL_{avsur,i}^n + B_{acc,i}^n)+1}^{OV_i^n} f_i^n(j) \cdot OSC \cdot [j - (B_{acc,i}^n + PL_{avsur,i}^n)]$$

subject to $OV_i^n \geq 0$

$$BL^n = \sum_{i=1}^K OV_i^n$$

Where:

OSC : oversales cost.

(b) the probabilities of the number j of survival reserving passengers on fare class i when decision period n ; $f_j^n(\bullet)$.

The function $f_j^n(\bullet)$ can be expressed in terms of binomial survival constant probability, which are often assumed (Bodily and Pfeifer (1992)). Rearranging and rewriting (1) gives

$$\max \sum_{i=1}^K \sum_{j=0}^{OV_i^n} \binom{OV_i^n}{j} (P_{real\ sur, i}^n)^j (1 - P_{real\ sur, i}^n)^{(OV_i^n - j)} \cdot f_i \cdot \min[j, (B_{acc, i}^n + PL_{av\ sur, i}^n)] \quad (3)$$

$$- \sum_{i=1}^K \sum_{j=(PL_{av\ sur, i}^n + B_{acc, i}^n) + 1}^{OV_i^n} \binom{OV_i^n}{j} (P_{real\ sur, i}^n)^j (1 - P_{real\ sur, i}^n)^{(OV_i^n - j)} \cdot OSC \cdot [j - (B_{acc, i}^n + PL_{av\ sur, i}^n)]$$

subject to $OV_i^n \geq 0$

$$BL^n = \sum_{i=1}^K OV_i^n$$

Where:

$P_{real\ sur, i}^n$: binomial survival constant probability on fare class i when decision period $n, i = 1, 2, 3, \dots, K$.

.3. A COMPREHENSIVE MULTIPLE-FARE SEAT ALLOCATION AND OVERBOOKING DYNAMIC MODEL

We combine the multiple-fare overbooking dynamic model and multiple-fare seat allocation dynamic model constructed by Cheng(1997). The multiple-fare seat allocation dynamic model is given by the following function.

(a) Multiple-fare without multiple seat bookings, and with both cancellations and no-shows probabilities

The function gives :

$$S^{n-1} = \begin{cases} S^n - 1 & \text{for } n > 0, S^n > 0, ACC \geq REJ \\ S^n + 1 & \text{otherwise} \end{cases} \quad (4)$$

$$ACC = f_i \cdot p_{sur,i}^n, \quad i = 1, 2, \dots, K \quad (5)$$

$$REJ = EMSR_{avsur}^{n-1}(S^n) \quad (6)$$

Where:

S^n : available seats when decision period n . The initial value is booking capacity(BC)

ACC : the expect revenue of accepting the reservation when decision period n .

REJ : the expect revenue of holding a seat from period $(n-1)$ to period zero after rejecting the reservation.

$p_{sur,i}^n$: survival probability on fare class i when decision period n ,
 $i = 1, 2, 3, \dots, K$.

$EMSR_{avsur}^{n-1}(\bullet)$: from period $(n-1)$ to period zero, the expected marginal seat revenue function considering both cancellations and no-shows probabilities.

(b) Multiple-fare with multiple seat bookings, and with both cancellations and no-shows probability

The function gives :

$$S^{n-1} = \begin{cases} S^n - \sum_{i=1}^K M_i^n & \text{for } n > 0, S^n \geq \sum_{i=1}^K M_i^n, ACC \geq REJ \\ S^n + \sum_{i=1}^K CA_i^n & \text{otherwise} \end{cases} \quad (7)$$

$$ACC = \sum_{i=1}^K M_i^n \cdot f_i \cdot P_{sur,j} \quad (8)$$

$$REJ = \sum_{j=1}^{\sum_{i=1}^K M_i^n} EMSR_{avsur}^{n-1} (S^n - \sum_{i=1}^K M_i^n + j) \quad (9)$$

Where:

M_i^n :the number of seats per request on fare class j when decision period n .

CA_i^n :the number of seats per cancellation on fare class j when decision period n .

To determine an optimal booking limit (BL^n) from the multiple-fare overbooking dynamic model, we rearrange and rewrite (4)–(6) and (7)–(9).

(a)comprehensive multiple-fare seat allocation and overbooking without multiple seat bookings

The function gives :

$$S^{n-1} = \begin{cases} S^n + (BL^n - BL^{n-1}) - 1 & \text{for } n > 0, [S^n + (BL^n - BL^{n-1})] > 0, ACC \geq REJ \\ S^n + (BL^n - BL^{n-1}) + 1 & \text{otherwise} \end{cases} \quad (10)$$

$$ACC = f_i \cdot P_{sur,i} \quad , i = 1, 2, \dots, K \quad (11)$$

$$REJ = EMSR_{avsur}^{n-1} (S^n) \quad (12)$$

(b) comprehensive multiple-fare seat allocation and overbooking with multiple seat bookings

The function gives :

$$S^{n-1} = \begin{cases} S^n + (BL^n - BL^{n+1}) - \sum_{i=1}^K M_i^n & \text{for } n > 0, [S^n + (BL^n - BL^{n+1})] \geq \sum_{i=1}^K M_i^n, ACC \geq REJ \\ S^n + (BL^n - BL^{n+1}) + \sum_{i=1}^K CA_i^n & \text{otherwise} \end{cases} \quad (13)$$

$$ACC = \sum_{i=1}^K M_i^n \cdot f_i \cdot P_{sur,i} \quad (14)$$

$$REJ = \sum_{j=1}^K EMSR_{avsur}^{n-1} (S^n - \sum_{i=1}^K M_i^n + j) \quad (15)$$

4. EXPERIMENTAL RESULTS

This model has been extensively tested on Taipei to Macau international airline of TransAsia airways' booking system in Taiwan. 26 flights' data are used for the comprehensive multiple-fare seat allocation and overbooking strategy models. The results are summarized in Table 1.

In terms of total revenue, our model increases 6% revenue in comparison with the rule-of-thumb approach of experienced staff, and increases 30.5% revenue in comparison with the model of Belobaba(1987). With respect to each flight revenue, our model increases 22 flights revenue in comparison

with the rule-of-thumb approach of experienced staff and increases all flights' revenue in comparison with the model of Belobaba. One major reason that is the comprehensive multiple-fare seat allocation and overbooking dynamic model consider the cancellation probability. The model is suitable for situation where a strict confirmation process is implemented which reduces the probability of no-shows, and increases the probability of cancellation.

Table 1. Compare different comprehensive multiple-fare seat allocation and overbooking strategy models unit:NT\$,

Strategies	Belobaba[1987]	This research	Rule-of thumb
Revenue of each flight	475,652(3)	564,164(1)	505,140(2)
	521,976(2)	565,400(1)	512,464(3)
	553,984(2)	564,020(1)	518,884(3)
	380,864(3)	562,548(1)	509,564(2)
	385,192(3)	554,224(1)	482,692(2)
	359,224(3)	552,512(2)	554,224(1)
	352,756(3)	502,384(1)	497,056(2)
	331,116(3)	547,376(1)	530,016(2)
	445,784(3)	512,704(1)	476,984(2)
	322,460(3)	546,616(1)	462,860(2)
	483,452(3)	542,476(1)	490,776(2)
	497,720(2)	552,512(1)	439,220(3)
	461,812(3)	558,980(1)	529,920(2)
	425,192(3)	545,284(1)	507,092(2)
	320,272(3)	547,852(1)	495,772(2)
	270,240(3)	525,976(1)	496,440(2)
	338,536(3)	546,616(1)	494,536(2)
	134,168(3)	520,316(1)	520,268(2)
	367,880(3)	547,376(1)	531,728(2)
	442,408(3)	504,808(2)	536,056(1)
	211,216(3)	539,292(1)	519,316(2)
	541,000(3)	573,960(1)	541,048(2)
	337,584(3)	466,284(2)	524,784(1)
	279,276(3)	494,252(2)	497,676(1)
	153,764(3)	513,468(1)	457,964(2)
331,212(3)	537,532(1)	518,412(2)	
Total	9,724,740	13,988,932	13,159,782
Percentage of the maximum	0.695	1	0.940

Note: () is to arrange each flight revenue in order

5.CONCLUSIONS

Airline companies may still fly with empty seats even though the booking demand for the flight is higher than its capacity. In order to reduce the number of empty seats, airline companies resort to overbooking. Through carefully controlled overbooking, the airlines can reduce the number of empty seats and construct an optimal revenue management.

This research develops a dynamic multiple-fare overbooking strategy model. It considers the competition of different fare classes with each other in zero stage. Then overbooking process can include the operation of variable bookings of multiple-fare class. It constructs multiple-fare penalty cost function that also better addresses the practical airline companies' operations under deny boarding situations. It better addresses the practical airline companies' operations under overbooking situations. Although this model has been extensively tested on an airline company booking system in Taiwan, the underlying approach provides a conceptual framework to handle a multiple-fare overbooking strategy model and a comprehensive multiple-fare seat allocation and overbooking strategy model.

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**ASSIGNING ARRIVING AND DEPARTING TRANSPORTERS
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1. BACKGROUND; THE PROBLEM

There are many facility operational planning/scheduling situations for which, within a given time window, arriving and/or departing transporters carrying units originating at the facility, terminating at the facility, continuing through on the same transporter, or transferring to another transporter over some intra-facility transfer route, must be assigned physical locations within the facility. The assignments may be made as part of an advance plan, or dynamically, e.g. shortly preceding the time window, perhaps while all arriving transporters are en route, in the context of a real-time decision support problem. It is proposed that the assignments consider desirable operational efficiency criteria for the facility and/or the transporters and/or the units. It is realized the dynamic version may be ill-advised if it is felt that repetitively transferred units should habitually have the same transfer route.

Examples are: (1) at an air/bus terminal, planes/busses arriving and/or departing with passenger/luggage units must be assigned gates between which units transfer, and (2) at a freight transfer terminal, freight vehicles arriving and/or departing with cargo units must be assigned docks between which units must be transferred.

The assignment of transporters to locations must consider the feasibility of each transporter being serviced at the alternative locations. Such feasibility should recognize transporter and unit needs such as physical compatibility with the different locations and approaches to them, maintenance, restocking, access/egress (e.g. ramps, conveyors), etc.

This paper deals with the assignment of transporters to locations according to a quantitative criterion. Suggested criteria consider measures for the transfer of originating units from the facility entrance(s) to their departing locations, plus the transfer of all terminating units from their arriving locations to the facility exit(s), plus the transfer of all transferring units over intra-facility location-to-location transfer routes. Such measures can be time, distance, or some combination thereof. Hereinafter the measure used is distance.

It is recognized that the problem may be trivial or worthy of little management attention in small low-activity facilities. It is likely to be more meaningful for large high-activity facilities wherein absence of an objective criterion for assignments may invite very inefficient ones.

1.1 Problem Solution Criteria and Key Assumption

Initially it is assumed that scheduled transporter arrivals and departures are such that, considering times to traverse distances between all locations to which transporters might be assigned, within the time window transfers can be made between all pairs of transporters. Under this “all-are-time-feasible” assumption, there is enough time for transfers (i.e. connections) between the latest arriving transporter and the earliest departing transporter. (See “Relaxing the All-Are-Time-Feasible Assumption” in Section 2. below re: ignoring this assumption.)

A first suggested criterion for assigning transporters to locations is that the sum of all individual transfer “costs” should be minimized. “Cost” for any one transfer is defined as number of units transferred multiplied by the distance between the locations involved in the transfer. Stated in this manner the problem is completely analogous to various other location, layout, and design problems which have been formulated as quadratic assignment models. The quadratic assignment model is in general known as a mathematical optimization (programming) problem which can be very difficult to solve. A number of approaches exists, ranging from 1) optimally solving a nonlinear integer programming problem, to 2) linearizing the model at the expense of adding additional integer variables/ constraints, and optimizing, to 3) using heuristic methods that can give good but perhaps non-optimal results for large problems within reasonable computer time.

This paper begins with the quadratic assignment model as a base formulation for a preferred first problem solution criterion. Then two different problem solution criteria are formulated, followed by relaxing the all-are-time-feasible assumption.

2. QUANTITATIVE FORMULATION AND EXAMPLE

As stated above, the problem of assigning transporters to locations so as to minimize the total cost of making transfers between transporters can properly be modeled as a quadratic assignment model. Quantitatively, the base model is:

Let:

t, u = indices for transporters whether terminating, continuing, or originating;

T = total number of transporters to assign to locations during the planning time window;

ℓ, m = indices for locations to which transporters may be assigned;

L = total number of locations to which transporters may be assigned;

Q_{tu} = the number of units transferring from transporter t to transporter u ;

$D_{\ell m}$ = the transfer distance from location ℓ to location m , with symmetric distances;

Λ_t = the set of all locations to which transporter t may be feasibly assigned;

T_ℓ = set of all transporters that may feasibly be assigned to location ℓ .

For making assignments, the decision variables are:

$x_{t\ell}$ which is to be set to 1 if transporter t is assigned to location ℓ and otherwise to be set to 0. These variables are defined for $t = 1, \dots, T$ and $\ell \in \Lambda_t$.

Given the above notation the quadratic assignment model is formulated as follows:

$$\text{Minimize } \sum_{\substack{t=1 \\ t \neq u}}^T \sum_{\substack{u=1 \\ t \neq m}}^T \sum_{\substack{\ell \in \Lambda_t \\ \ell \neq m}} \sum_{m \in \Lambda_u} Q_{tu} D_{\ell m} x_{t\ell} x_{um} \quad (1)$$

$$\text{subject to: } \sum_{t \in T_\ell} x_{t\ell} \leq 1 \quad \forall \ell = 1, \dots, L \quad (2)$$

$$\sum_{\ell \in \Lambda_t} x_{t\ell} = 1 \quad \forall t = 1, \dots, T \quad (3)$$

$$x_{t\ell} \in \{0, 1\} \quad \forall t = 1, \dots, T \text{ and } \ell \in \Lambda_t \quad (4)$$

Equation (1) calculates the total cost of all transfers as a function of the assignment variables. Each inequality (2) ensures that at most one transporter is assigned to any location. Each equation (3) ensures that each transporter is assigned to exactly one location. The constraint (4) states that the assignment variables can take only the values 0 or 1.

It is noted that the model (1), ..., (4) accommodates only the transfer costs for transferring units from transporter to transporter. To consider as well transfers from an initial location (e.g. entrance) at the facility to a transporter, and from a

transporter to a final location (e.g. exit) at the facility, it is presumed that the T^{th} transporter is a dummy that is pre-assigned to both the entrance and exit. It is also presumed that the L^{th} location is a dummy location occupying both the initial and final locations in the facility. Multiple entrances/exits may be accommodated by extending this concept.

The problem is thus modified as follows: the decision variables are defined only for $t = 1, \dots, T-1$ and $\ell \in \Lambda_t$, and none of the sets, Λ_t , would contain L , and the model becomes:

$$\text{Minimize} \quad \sum_{t=1}^{T-1} \sum_{\ell \in \Lambda_t} (Q_{tT} D_{tL} + Q_{Tt} D_{L\ell}) x_{t\ell} + \sum_{t=1}^{T-1} \sum_{u=1}^{T-1} \sum_{\substack{\ell \in \Lambda_t, m \in \Lambda_u \\ \ell \neq m}} Q_{tu} D_{\ell m} x_{t\ell} x_{um} \quad (1a)$$

$$\text{subject to:} \quad \sum_{\ell \in \Lambda_t} x_{t\ell} \leq 1 \quad \forall \ell = 1, \dots, L-1 \quad (2a)$$

$$\sum_{\ell \in \Lambda_t} x_{t\ell} = 1 \quad \forall t = 1, \dots, T-1 \quad (3a)$$

$$x_{t\ell} \in \{0, 1\} \quad \forall t = 1, \dots, T-1 \text{ and } \ell \in \Lambda_t \quad (4a)$$

The first term in the objective function calculates the cost of all transfers to all real transporters from the dummy transporter plus the cost of all transfers from all real transporters to the dummy transporter. The rest of the model is unchanged except for the number of decision variables and constraints.

To illustrate application of the model, consider operations at an airline terminal/hub. Indeed, airport passenger transfers between flights have escalated noticeably with air travel growth and since hub airports were introduced. Transfer activity may be inferred to be heaviest at “central” and hub airports within a country or continent. One airline spokesman has suggested that for a central and hub airport, as many as 85% of enplanements may be from passengers transferring from arriving connecting flights.

Suppose that over a specified time window (e.g. “bank” in airline terminology) six airliners are to be assigned to six gates at the terminal. For simplicity we suppose management is only concerned about the transfer distance of passengers who must change planes as opposed to those originating or terminating at the terminal. The simplification means we may use the first model (1), ..., (4). The data for the problem are given in the tables below.

TABLE 1
THE NUMBER, Q_{tu} , OF
TRANSFERRING PASSENGERS

from/to	flt 101	flt 102	flt 103	flt 104	flt 105	flt 106
flt 101	0	40	30	20	0	5
flt 102	10	0	10	5	0	40
flt 103	0	0	0	0	0	0
flt 104	50	0	10	0	0	5
flt 105	10	5	20	5	0	10
flt 106	20	20	20	20	0	0

Note: Flight 105 is a terminating flight and thus it receives no transfers while Flight 103 is an originating flight and thus it offers no transfers.

Source: Author-fabricated data.

TABLE 2
DISTANCES, D_{lm} (IN YARDS),
BETWEEN GATES

from/to	gate 1	gate 2	gate 3	gate 4	gate 5	gate 6
gate 1	0	80	130	190	230	300
gate 2	80	0	50	110	150	220
gate 3	130	50	0	60	100	170
gate 4	190	110	60	0	40	110
gate 5	230	150	100	40	0	70
gate 6	300	220	170	110	70	0

Source: Author-fabricated data

Feasible gate assignments lead to the set definitions given below. These feasible assignments are based on a hypothetical scenario in which flights 103 and 106 are large planes that cannot be accommodated at gates 2 or 5. Also flight 101 arrives before gate 5 is cleared from a previously departing flight (not one of the six) so it cannot be assigned there and flight 104 cannot be assigned to gate 2 for a similar reason. Given this scenario the feasible gate sets for each flight is as follows:

$$\Lambda_{flt101} = \{\text{gate 1, gate 2, gate 3, gate 4, gate 6}\}$$

$$\Lambda_{flt102} = \{\text{gate 1, gate 2, gate 3, gate 4, gate 5, gate 6}\}$$

$$\Lambda_{flt103} = \{\text{gate 1, gate 3, gate 4, gate 6}\}$$

$$\Lambda_{flt104} = \{\text{gate 1, gate 3, gate 4, gate 5, gate 6}\}$$

$$\Lambda_{flt105} = \{\text{gate 1, gate 2, gate 3, gate 4, gate 5, gate 6}\}$$

$$\Lambda_{flt106} = \{\text{gate 1, gate 3, gate 4, gate 6}\}$$

The optimal solution to this problem was found using the general purpose non-linear spreadsheet model solver available within Microsoft EXCEL. The EXCEL solver allows one to define and solve a quadratic assignment model. Although details are not given here, efficient spreadsheet implementation may take advantage of matrix multiplication tools. The solution was found with some

difficulty, requiring restarts with different values for parameters of by the solver.

As an alternative, the problem was also reformulated and solved using LINDO Systems Inc.'s LINGO non-linear mathematical programming software package. As strongly advocated by LINGO proponents and others, the quadratic assignment model may be converted into an equivalent linear, integer program by introducing a large number of additional 0-1 variables and additional constraints. Such conversion provided for the LINGO approach to reliably find an optimal solution.

Both the EXCEL and LINGO solutions cost 36400 passenger yards, and assigned:

flight 101 to gate 4	flight 102 to gate 2	flight 103 to gate 6
flight 104 to gate 5	flight 105 to gate 1	flight 106 to gate 3

The largest transfer cost for a single route was 6000 passenger yards, namely, 20 transferring units from flight 105 at gate 1 to flight 106 at gate 3.

2.1 Problem Formulation Alternatives

A second suggested criterion recognizes that a solution that minimizes total cost may use, as one of its transfer routes, one with a very large transfer cost. To avoid using such an extreme transfer cost route, or any of the largest transfer cost routes, a different criterion would be to minimize the maximum transfer cost encountered by any particular pair of transporters. Such a criterion might be appealing from an equity point of view. For example, in the airport gate problem this criterion would produce solutions that would not unnecessarily inconvenience the passengers of one flight in order to improve the convenience of the passengers of other flights.

To model this problem the following additional notation are introduced:

$$\bar{Q}_{tu} = \text{Max}(Q_{tu}, Q_{ut}),$$

K = any sufficiently large number.

and an additional decision variable, c , the maximum transfer cost, is defined.

To ensure that c actually equals the maximum transfer cost a series of constraints are added to the problem. By definition a maximum transfer cost is greater than or equal to all individual transfer costs. This leads to linear constraints of the following type:

$$\bar{Q}_{iu} \sum_{\ell \in \Lambda_t} D_{\ell m} x_{\ell t} \leq c + K(1 - x_{um}) \quad (5)$$

When assignment variables satisfy the assignment constraints (2), (3), and (4) the summation on the left-hand-side of constraint (5) calculates the distance between location m and the location to which transporter t is assigned. Thus the entire left-hand-side calculates the highest cost of transfers to or from transporter u assuming u is assigned to location m . If u actually is assigned to m then the factor K is removed from the right-hand-side of the constraint which in turn causes the constraint to require c to be at least as large as the requisite cost. If u is not assigned to m then the constraint is irrelevant for determining c , and in this case the factor K is not removed so that the constraint is satisfied by any non-negative value of c . For purposes here K may be set equal to the maximum possible transfer cost.

A constraint of type (5) is required for every pair of transporters and every possible location. In the case when any transporter can be assigned to any location and there are T real transporters and L locations available for assignment of transporters, the number of constraints of this type that are needed is $LT(T+1)/2$. If not all assignments are feasible then fewer constraints are needed. The minimax model counterpart to the first problem, (1) through (4) may now be stated.

$$\text{Minimize } c \quad (6)$$

Subject to:

$$\bar{Q}_{iu} \sum_{\ell \in \Lambda_t} D_{\ell m} x_{\ell t} \leq c + K(1 - x_{um}) \quad \text{for } t=1, \dots, T-1; \quad u=t+1, \dots, T; \quad \forall m \in \Lambda_u \quad (7)$$

$$\sum_{\ell \in \Lambda_t} x_{\ell t} \leq 1 \quad \forall \ell = 1, \dots, L \quad (8)$$

$$\sum_{\ell \in \Lambda_t} x_{\ell t} = 1 \quad \forall t = 1, \dots, T \quad (9)$$

$$x_{\ell t} \in \{0, 1\} \quad \forall t = 1, \dots, T \text{ and } \ell \in \Lambda_t \quad (10)$$

2.1.1 Illustrative Example Reconsidered Using the Minimax Criterion:

Considering the previous problem it is noted that if any plane could be assigned to any gate the number of constraints of type (7) is 90, but given the flight-to-gate feasibilities in this example only 73 such constraints are actually needed. For the

example problem the minimax criterion version was quickly and reliably solved using the EXCEL solver, giving the following solution:

flight 101 to gate 4	flight 102 to gate 2	flight 103 to gate 3
flight 104 to gate 5	flight 105 to gate 6	flight 106 to gate 1

The minimax route transfer cost was 4600 passenger yards, namely 20 transferring units from flight 106 at gate 1 to flight 104 gate 5. No minimax solution was attempted using LINGO.

This maximum route transfer cost is 23% less than that for the minimum total cost criterion problem solution. In general, the maximum route cost for the minimax cost criterion problem solution would be expected to be no more than that for the minimum total cost criterion problem solution.

The total transfer cost for this minimax transfer cost problem solution was 39212, 7% higher than that for the minimum total cost criterion problem solution. In general the total cost for the minimax cost criterion problem solution would be expected to no less than that for the minimum total cost criterion problem solution.

A third suggested criterion recognizes that a solution for the minimum total cost criterion may use the transfer route with a very large transfer distance. It may be desirable to avoid using this extreme distance route, or possibly any large distance routes. A solution for a criterion of minimizing the maximum distance used by any transfer route may be obtained by solving the problem under criterion 2 with the number of transferring units defined as 1 for each active transfer. As might be intuitively expected from problem data, since there is a transfer in at least one direction between every pair of flights, the minimized largest transfer distance is 300 yards.

2.1.2 Relaxing the All-Are-Time-Feasible Assumption:

Consider a case in which at least one unit must be transferred from transporter t to transporter u . Depending on the location assignments for these two transporters the time to make the transfer could be greater than the time between the arrival of t and the departure of u . This is a situation in which the assumption is not true. The absence of this assumption means that the location assignments must be constrained further than they have been in any of the preceding models. To model this situation some additional data are needed. In particular, we suppose that the time to make a transfer is a known function of the distance and the number of units transferred.

Denote the function $f(Q_{tu}, D_{tm})$, which is the time to transfer Q_{tu} units when t is assigned to location ℓ and u is assigned to location m . Further, let S_{tu} be the amount of time available to transfer all the units from t to u considering their respective arrival and departure times. Then

$$\sum_{t \in \Lambda_u} f(Q_{tu}, D_{tm})x_{t\ell} \leq S_{tu} + K(1 - x_{um}) \quad \forall m \in \Lambda_u \quad (11)$$

One will note the similarity of these constraints with those introduced for the minimax formulation, and they work in the same way. A sufficient value for the factor, K , is the transfer time between the locations that are the greatest distance apart. Any number of constraints of type (11) could be added to any one of the three previously introduced models as necessary. No computerized solutions of this formulation were attempted.

3. PREVIOUS PROBLEM RECOGNITION

The above problem might be called the “Transfer Location Assignment Problem (TLAP)”. Its quadratic assignment model formulation is believed to have been originally conceived by the first author who investigated it in an airport gates context using LINGO software in 1991. It was then submitted to LINGO developers for computer model streamlining, and has since appeared in LINGO problem sets which contain sample quadratic-assignment model applications.

Previous recognition/formulation of the problem, especially in an airline gates context, was sought by World-Wide-Web-computer-searching two bibliographies. The Annual Comprehensive Index of the Institute for Operations Research and Management Science (“INFORMS”) was searched using the following key word sequences:

terminal gate assignments, airline gates, airport gates,
gate assignments, quadratic assignment problem, minimax assignment

This index references numerous publications from 1982 to 1996. Also searched were papers from proceedings of annual AGIFORS (Airline Group of the International Federation of Operations Research Societies) meetings, through AGIFORS’ web site catalogue of such proceedings. The search “hits” revealed a few integer linear programming formulations of the problem, e.g. . Mangoubi and Malthaisel (1985). However no quadratic assignment formulations of the problem were revealed. Quadratic assignment formulations were not identified in either of the comprehensive references Teodorovic(1988) or Richter (1989).

4. CONCLUSIONS AND DISCUSSION

Assigning transporters to terminal locations must address numerous managerial and operational considerations. However in many applications the assignment should not neglect the “costs” of accomplishing the transfer. The problem formulations presented above provide for applying different solution criteria for assignments. The computerized approaches demonstrated may be sufficient for infrequently solving small problems. Frequent or larger problem solutions required in a (perhaps intra-day) Decision Support System context invite investigating choices from among specialized available quadratic assignment model solution computer packages.

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Topic Area A4: Airports and Aviation

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NAV CANADA's Provision of Air Navigational Services in Northern and Remote Areas

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1.0 INTRODUCTION

In 1996, Canada became the first nation to fully commercialize its air navigational system (ANS). Other jurisdictions had placed their ANS under a government controlled and owned entity, but the Canadian solution went further. The assets and personnel were transferred from Transport Canada (TC) to a non-share corporation called NAV CANADA, governed by a board of directors drawn from stakeholder groups. Transport Canada retained a purely regulatory role, ensuring that safety standards were maintained.

In the process of negotiating the transfer, some argued that the nascent ANS corporation should only be responsible for the southern airspace, while TC should continue to manage the northern and remote areas, where low traffic densities and high operating costs make full cost recovery for the system infeasible. This view was rejected, and the ANS transferred in its entirety. Northern stakeholder groups were alarmed that this might mean that full cost recovery would be implemented in their fragile economy. They lobbied for exemptions in the Bill C-20¹ which would protect northern interests.

This paper concerns the lobbying process, the safeguards in the ANS Act, and the early issues in implementing a commercialized ANS in the northern and remote regions.²

1.1 Origins of Commercialization

In the federal budget tabled in February of 1994, the government stated its intention to study the potential for commercialization of the ANS in order to improve efficiency and achieve long-term savings for the Crown. This was part of a comprehensive rethinking of government involvement in transportation, which included commercialization of port facilities or transfer to provincial control, transfer of airports to local operating authorities, and the privatization of the Canadian National Railroad (a Crown corporation). Air Canada had been privatized in 1988-89 under the Progressive Conservatives, but the movement toward decreased government control was, if anything, accelerated under Liberal Transport Minister Doug Young.

In part, the government was responding to the views of its stakeholders. The air traffic controllers union (CATCA), the airline pilots unions, the Air Transport Association of Canada (ATAC) which represents air carriers, and the Canadian Business Aircraft Association

¹ Statutes of Canada 1996, Chapter 20, *An Act respecting the commercialization of civil air navigation services*, (hereafter C-20 or the ANS Act).

² The author currently manages the NWT CARS program, which is administered for NAV CANADA by the Government of the Northwest Territories. In 1997, he also represented the Consumers' Association of Canada on the federal Transport Minister's Committee on Air Policy Issues. This paper and its conclusions are those of the author and do not necessarily represent the views of the Government of the Northwest Territories, NAV CANADA, or the Consumers' Association of Canada.

(CBAA), had lobbied for the ANS to be run as a business. The idea had also been proposed by a Royal Commission on National Passenger Transportation,³ and a Ministerial task force.

At the time, the ANS employed over 6000 people, including 2300 air traffic controllers, 1000 Flight Service Specialists, and 1100 electronic technicians. TC maintained 105 Flight Service Stations and 55 control towers, as well as the radio aids to navigation (navaids), radar, and data processing systems required for the work.⁴ The system provided services for the world's second largest country, and a considerable portion of the North Atlantic. Annual expenditures were \$800 million.⁵

The system was funded by an Air Transportation Tax (ATT) which was levied on passenger tickets. This raised about \$550 million in 1994. Revenues from fees on international flights generated another \$50 million. The remainder of the expense was funded from general tax revenues (TP12203E: 6).

The general view of the user community was that the system was underfunded, and would not keep up with future requirements. Fiscal restraint in the federal government gave little comfort that new appropriations would be found as soon as they were required. At the same time, there was a feeling that government procurement, staffing, training, and labour relations processes were far too cumbersome and added unnecessary cost to the system.

1.2 Structure of the Corporation

The term "commercialization", as is it used by the Canadian government, refers more to a series of desirable traits than to a specific structure. A commercialized ANS would manage resources and people efficiently, be responsive to user needs and be able to rapidly adopt new technologies, would make decisions on commercial principles, and would have access to capital markets (TP12202E: 9). Several models were discussed for the new entity, including a Special Operating Agency of government, a Crown Corporation, a government owned - company operated enterprise, a mixed enterprise, a not-for-profit corporation, and a fully privatized enterprise (TP12202E: 20-24).

In the end, a not-for-profit corporation, reporting to a stakeholder Board of Directors was chosen. NAV CANADA was incorporated as a non-share capital corporation. All profits generated must be reinvested in the corporation, used to pay down debt, or repaid to the users in the form of decreased fees. The Board is composed of five members nominated by the industry, two by unions, three by the federal government, and four by the board itself, plus a Chief Executive Officer.⁶ Directors are required to be Canadian citizens, but may not be

³ Canada Communications Group. *Directions*. Volume 1, pp. 126-127.

⁴ Transport Canada "Discussion Paper Number 1: Principles and Options for Commercialization" TP12203E, Appendix A, in *The Study of the Commercialization of the Air Navigation System in Canada*, p. 5.

⁵ Costs and prices in this paper are expressed in Canadian dollars.

⁶ *Commercialization of the Air Navigation System*, page 8.

elected officials or civil servants of any level of government, or employees or directors of organizations which are major suppliers or customers of NAV CANADA.

The ANS consultation process began in late summer of 1994. The ANS Commercialization Study Team toured the country consulting with stakeholders. A meeting with the Northern Air Transport Association (NATA) was scheduled in Whitehorse, capital of the Yukon Territory, on September 15 (TP12203E, Appendix A, p. 26). NATA is the primary organization of northern aviation operators. Although not all operators participate in NATA, the "majors" -- Canadian North, NWT Air, and First Air -- are members, as well as many smaller fixed wing and helicopter operations.

1.3 Northern and Remote Regions

The "northern and remote regions" referred to in the document include the Northwest Territories, Yukon Territory, northern Quebec, and the northern parts of several provinces.⁷ The area is very sparsely populated, and consists of widely scattered small settlements, separated by some of the most inhospitable terrain on the planet. Most of these settlements are wholly dependent on air transport. There is little substitution possible with other modes, since most communities are not linked by roads, and the short shipping season of the Arctic restricts most coastal communities to a single barge sea-lift per year.

The harsh operating environment produces a tough breed of aviators, the "bush-pilots". The great distances mean that few alternate airports are available. Harsh and unpredictable weather increases risks.

The low population and large distances involved create a low traffic density for air transport operators. High operating costs are often barely covered by revenues. Often there is little effective competition because, while there may be low barriers to entry, the low traffic volumes do not allow a second operator to fly profitably. Demand for staples is inelastic, but other items, such as fresh fruit, vegetables and dairy products have higher price elasticity of demand. The typical northern operator makes profit, if at all, on freight, rather than passengers. Fresh food costs are subsidized by a program called "food mail".⁸

The north is still economically dependent on the southern tax base. Its economy, based on natural resource extraction and harvesting of wildlife is not sufficient to sustain it. Living costs are very high. Transportation costs are a major component of goods prices. Fuel and energy costs are very high, both because of the severe climate, and because of transportation costs.

The future high potential of the resource base cannot be exploited without infrastructure. The withdrawal of the federal government from infrastructure such as airports, and deficit-cutting

⁷ The communities are specified in Schedule A of the *Department of Transport Agreement*, between NAV CANADA and Transport Canada.

⁸ This program is run by the federal Department of Indian Affairs and Northern Development (DIAND).

by the territorial governments has put a severe strain on resources. At the same time, the aircraft which are projected to replace some of the aging types now in service will require longer runways. New standards for snow and ice contamination suggest that some investment in runways will be required, even to accommodate the existing fleet.

The discussion papers which formed the basis for public consultation contained a clear recognition that a subsidy program of some kind was inevitable and acknowledged the need to “insulat[e] an ANS corporate entity from the potentially costly and conflicting roles of managing in commercial and social environments simultaneously (TP12204: 12).⁹

1.4 Bill C-20

Recognizing the unique problems in the northern regions, the ANS Act included safeguards. These were not added capriciously, but as a consequence of determined lobbying on the parts of territorial governments and northern operators. In addition to the safeguards in legislation territorial governments felt that they were also given verbal assurances which went beyond this.

One source of comfort for the northern stakeholders was that the NAV CANADA Board of Directors, even before its official inception, was headed by John Crichton, the President of ATAC.¹⁰ Mr. Crichton had many years of association with First Air, which operates the most extensive route system in the north, including long-haul jet routes from the south, and smaller volume turboprop services throughout most of the Northwest Territories.

The assurances contained in the Act are encapsulated in the Summary, which presumably provides guidance to the intent of the document, since it is meant as an executive summary for members of parliament, states that among the key components of the enactment is:

the preservation of air navigation services to northern and remote communities, including a special process involving provincial and territorial governments for service reductions proposed by NAV CANADA

The actual assurances are more specific. With respect to fees levied for service (charging principles), the legislation states that:

charges for designated northern or remote services ... must not be higher than charges for similar services utilized to a similar extent elsewhere in Canada
[C-20: 35. (1) (g)].

⁹ This concern reflected the sentiments of the Airways Corporation of New Zealand, which had prepared a working paper on the international experience (TP12205E), and which operated as a State Owned Enterprise in a much more interventionist government structure.

¹⁰ On November 18, 1997, Crichton became President and CEO of NAV CANADA, replacing Ken Copeland. He resigned as President and CEO of ATAC and Chairman of the Air Transport Security Corporation, as these would conflict with his new duties.

This reflects the most central concern of the stakeholders at the time, which was that the ANS operator would attempt to extract full cost recovery at the site level, which would make the costs on many routes too high for the delicate market to bear.

The complete dependence of northern communities on air transport was also recognized. Northern and remote services are guaranteed as part of the requirement to provide “Humanitarian or Emergency Flights” in the event of a work stoppage by NAV CANADA employees (C-20: 73 (1) definitions, 74).

In addition, the Act imposed a notification and consultation requirement on NAV CANADA. Where the operator of the ANS (“the Corporation”, in the Act) proposes a termination or reduction of services, and this will affect “a significant group of users or residents in a material way”, it must notify affected parties of its intent (C-20: 18). The Corporation may only proceed with such changes if, within 45 days, it has received no notice of rejection from the provincial government.¹¹ In the event that a province does reject the proposal, or the users have rejected it, the Corporation may only implement it with the approval of the federal Minister of Transport (C-20: 20). The Corporation is not entitled to compensation if the Minister does not approve the change in service (C-20: 20 (2)).

The Ministers of Transport or Defence may also direct the Corporation to provide new service at northern or remote locations (C-20: 24 (1)), but in this case, the crown must compensate NAV CANADA for any losses sustained in complying with the direction (C-20: 31).

The legislation also required the Corporation to set out, within one year after the transfer date, its Level of Service (LOS) Policy (C-20: 23). This must then be applied consistently, although it may be revised from time to time. Where services are requested in excess of the LOS Policy, these may be provided if a consensus of users is in favour of it, but such services will be charged out in addition to existing charges (C-20: 23 (5)).

2.0 THE LEGISLATION IN PRACTICE

The ANS Act imposed a rapid timetable on NAV CANADA. It had to develop and publish LOS Policies by the first anniversary date of transfer, as well as announcing a fee structure which would be phased in as the Air Transportation Tax (ATT) was phased out.¹²

¹¹ The Act uses the word provincial in most cases, but this is understood to also include the two territorial governments of Yukon and NWT.

¹² Users have pointed out that the tax is not eliminated, but merely reduced to zero, implying the ability of future governments to raise it again. This remains a concern in an industry already subject to heavy taxation.

2.1 Fees and Charges: The Issues

The first test of the legislation came in early summer of 1997, when NAV CANADA announced its proposed fee structure for phase one. On the surface, the changes made were uncontroversial, at least with the major carriers who operated in the southern domestic airspace and internationally. The proposal shifted the charging basis from a tax based on passenger tickets (ATT) to a fee based on maximum take off weight (MTOW) of the aircraft and distance.¹³ At the same time, terminal charges were assessed on aircraft departing aerodromes served by NAV CANADA units.¹⁴

The new fees were to be introduced in two phases. During phase one, planned to commence on 1 November 1997, the large commercial aircraft were to be charged one half the fee, with the remaining costs met by ATT. By November of 1998, full fee implementation would take place, and the ATT reduced to zero. In the second phase, smaller aircraft would also be charged fees.

The Act had recognized the need to switch from a tax base to a fee structure, and had included a number of constraints on the nature of fees, such as safeguards against discriminatory imposition of costs, while attempting to allow the Corporation as much flexibility as possible in going about its business. NAV CANADA was also constrained by International Civil Aviation Organization (ICAO) charging principles, and by the need to be consistent with international practice.

One aspect of the change which was certain to be addressed was the fact that ATT applied only to the passenger carriers. Scheduled or charter carriers generated significant revenues to the government (and in the transition period, NAV CANADA) through the ATT applied to passenger tickets,¹⁵ while all-cargo operators using the same type of aircraft were not charged. The major scheduled carriers objected to the "free-riding" of cargo operators. General aviation and operators using aircraft of less than 8 tonnes were also exempt from ATT.

Northern operations have certain structural features which made the transition to MTOW-based fees more complex. First, northern operators generally use aircraft which are larger than would be used on a similar route in the south. Route segments are generally longer than they would be in the south, and the relative lack of alternates implies a need for greater range. Second, northern operators tend to use combi configurations. Profitability for northern carriers is a function largely of the freight they carry. Third, freight is uni-directional. Almost all aircraft carry significant freight loads northbound, but there is next to no southbound freight.

¹³ The proposed enroute charging formula was $\$0.02174 \times \text{Distance} \times \text{MTOW}^{0.9}$ in phase one.

¹⁴ The proposed terminal charge was $\$7.74 \times \text{MTOW}^{0.9}$ in phase one.

¹⁵ The ATT calculation for a domestic or transborder flight is a fixed fee of \$6.00, plus 7 per cent of the price of the air fare, to a maximum of \$55.00. International (other than US) flights are charged a \$55.00 fee.

A northern operator, therefore, typically carries a section or two of passengers and a number of freight pallets northbound, and returns with a low passenger load factor, but no freight. Under the previous regime, the ATT applied to the passengers, but not the freight, and was similar whether the aircraft was southbound or northbound.

Under the NAV CANADA fee structure, the reduction of ATT may reduce a southern operator's total ticket price. The application of the MTOW-based fees and terminal fees is off-set by reductions to ATT, and total average ticket cost may even decline. For the northern operator, since relatively fewer passengers are carried, the ATT reduction does not come close to off-setting the MTOW-based fees and, as operators were quick to point out, are applied equally to aircraft which are southbound, carrying no freight to off-set costs.

A second concern was raised by the imposition of terminal charges at Community Aerodrome Radio Stations (CARS). While NAV CANADA provides ANS services through ATC towers and Flight Service Stations (FSS), it also funds another service at smaller airports. The CARS are operated by territorial governments, the government of Quebec. The three types of ANS service are very different. Towers provide separation between aircraft in the zone, and control ground vehicles, but provide only limited weather services. Flight Service Stations provide an aerodrome traffic advisory service identifying conflicting air traffic, manage ground vehicle movements, and also provide a broad range of flight planning and weather briefing services. CARS provide basic advisories of known traffic, and limited weather information, but no weather or flight planning briefings. The primary purpose of the CARS is to provide the weather observations necessary to support a terminal forecast (TAF), and current weather for arriving and departing aircraft.

The CARS system is staffed by observer/communicators who are recruited in their communities, trained in radio procedure and weather observation at Aurora College in Fort Smith, and then return to their communities to work. The system serves the basic need for reliable weather observations, at a relatively low cost, and using a northern and largely native workforce.

Some users objected to the requirement that they pay user fees at CARS which were identical to those being charged at international airports, where ATC terminal units existed. Service levels had been dropping in the north even while Transport Canada was still operating the ANS. NATA complained that while these terminal and enroute charges might be appropriate in the south, where a full range of services including weather and ATC radar were available, it was unreasonable to pay the same fees for the relatively spartan services provided in the north.

2.2 Carrier Reaction and NAV CANADA Response

The publishing of the new fee structure drew a rapid response from the northern flyers. NWT Air, in its initial CBC radio interview, suggested that this would result in a 20 per cent increase in freight rates. Certainly, NWT Air was likely to see a large impact. Their fleet consisted of several B737 combi aircraft equipped for gravel runways, and a Hercules

transport aircraft. The size of the aircraft, and the relative importance of freight to the bottom line, made them particularly vulnerable.

Other carriers and stakeholders were quick to enter the skirmish. Transportation costs are always a political “hot button” in the north, and politicians and native groups reacted with increasing alarm.

NAV CANADA reacted with some degree of surprise to these assertions. While some impact would be felt by any carrier for whom freight was a major component of the business, this impact was generally considered to be low. The proposal also had the potential to reduce overall ticket prices for the major carriers, as cargo operations were now required to carry their share of the burden. The generally higher operating costs of smaller carriers would mean that the increases, as a percentage of revenue, would tend not be significantly different than they would be for the majors. Finally, if NAV CANADA succeeded in reducing system costs, these savings would eventually be passed down to the users. On the whole, the equity and transparency of the system were both improved by the proposal.

The protections afforded under the Act for intervention by territorial/provincial Ministers of Transportation provided a basis for a concerted effort led by the Government of the Northwest Territories (GNWT). The NWT was clearly the most affected jurisdiction, and the government sought support from other provincial transportation ministries. It also coordinated its response with that of NATA, and the individual carriers. Another ally was the federal Department of Indian Affairs and Northern Development (DIAND). The DIAND food mail subsidy program was “capped” by budget restraint measures, and could not accommodate a large increase in freight costs. Any such increase would not be buffered, and would be borne by consumers in the least economically developed region of the country.

The GNWT invited NAV CANADA to present a briefing on its proposals at a meeting of the Airline Consultative Committee (ACC), which is a regular meeting between the Arctic Airports division of GNWT and the carriers it serves. The northern carriers put forth their position rather forcefully, and were supported by the Assistant Deputy Minister of Transportation (GNWT), and members of the department’s operating arm, Arctic Airports, and its transportation planning group.

NAV CANADA had doubts that the impact was nearly as high as some stakeholders felt it was.¹⁶ The carriers, in the height of the profitable summer season, had limited resources to do the sort of route by route analysis which was required. NAV CANADA, on the other hand, did not have the financial data required for the work. Eventually, the parties shared their analyses, and came to the conclusion that the initial indications were high. First Air would later attribute price increases of 3 per cent on passenger tickets and 5.5 per cent on freight to

¹⁶ NWT Air was later quoted as estimating the range from 20-30 per cent, and this range became widely quoted (“New Fees mean ‘staggering’ jump in air freight rates”, Nunatsiak News, August 1, 1997, p. 3).

the impact of phase one fees.¹⁷ The airline indicated that in late 1997, its scheduled services were running at a loss.¹⁸ By NAV CANADA's calculations, the net impact on First Air's operations would be close to 3 per cent of operating revenues, but this would represent an additional cost to northern consumers of \$2 million per year.¹⁹

On August 13th, NAV CANADA announced changes to the proposal. The implementation of phase one fees was deferred until March 1998 to allow the carriers more time to reprogram their computer reservation systems for the tax changes. CARS were exempted from terminal charges for the period from March 1 until November 1, 1998, and NAV CANADA indicated that this exemption might later be extended, based on the results of user consultations. The aircraft size to which phase one fees applied was raised from 5.7 metric tonnes to 8 tonnes, again until November 1, 1998.²⁰ These changes did not address the main cost issue, which was the impact of switching the charging basis from the ATT to user charges based on MTOW. The exemption of CARS terminal charges was of greatest significance to First Air, which has the largest route system of any carrier operating in the NWT.

The second phase user charges are a more difficult matter, both in terms of equity and ease of administration, and will require considerable consultation with stakeholders. The phase two fee structure applies to smaller aircraft of types used by bush operators and private aviators. It is to be implemented in November 1998, at which time NAV CANADA will operate on a full cost recovery basis, and the ATT will be reduced to zero.

In this case, NAV CANADA is faced with a conundrum. Ideally, it would charge small operators on a charging formula similar to the one established for the larger aircraft. Practically, however, this presents the problem of significantly increasing bureaucratic overhead and complexity, for a relatively small increase in revenues. One approach under discussion is some form of flat fee, but this is not without pitfalls. Small operators and private pilots are very sensitive to the magnitude of the fees, while the large operators, who provide the bulk of the revenues (and are heavily represented on the board) may not wish to subsidize the system and, to some extent, their competition.

Another scenario was a tax/levy on aviation gasoline, which would be paid to NAV CANADA. This would provide a user charge based on activity without the administrative complexity of a per-use charge, but many of the types in commercial operation are turboprop aircraft, so some arrangement such as a flat fee would still be required. This method also

¹⁷ "First Air Prices Take Off" in News/North, 24 November 1997, p. A23. The NAV CANADA increases were to take effect on 1 March, 1998. At the same time, the airline also announced tariff increases of 3 percent on passenger fares and 4.5 per cent on cargo, effective 1 January, 1998, which it attributed to overall economic conditions in the north.

¹⁸ "Our Fares are Going Up in the New Year. We'd Like You to Know Why." Paid advertisement News/North, 1 December, 1997.

¹⁹ User Charges: Presentation to Northern Air Transportation Industry, Northern Governments, November 26, 1997.

²⁰ NAV CANADA News Release No. 17/97.

charges the operator whether the NAV CANADA service is used or not. Helicopter operators may seek a different formula than fixed-wing, since their bush operations often make little use of NAV CANADA services.

No matter what formula is used, however, it will not satisfy all stakeholders. The consultation for phase two fees is to be completed by summer the of 1998, for implementation in November.

2.3 Levels of Service Policy: The Issues

The rapid timetable in the Act also required NAV CANADA to consult with stakeholders and to publish a Levels of Service (LOS) Policy by the first anniversary of ANS transfer (C-20: 23). The LOS issues were vital to NAV CANADA's rationalization program nationwide, but again the north was strongly impacted.

Level of Service implies a set of services to be provided at a location, and is linked to traffic levels. For example, an ATC tower is justified by annual movements above 60,000, while a FSS is justified by traffic exceeding 40,000 movements, but less than 60,000.²¹ By these criteria, the tower at Yellowknife, the capital of NWT, was barely viable. The tower in Whitehorse Yukon's capital, recorded only 42,575 in 1996, though in earlier years this total had exceeded 50,000.²² Complexities in traffic management were cited as a rationale for retaining the facility.

None of the FSS in the NWT met the movements criteria. This situation had been acknowledged by all parties for some time. Transport Canada, when it operated the ANS, had earmarked the majority of the NWT's Flight Service Stations for closure. In the early 1990s, it had closed the FSS at Coppermine (Kugluktuk) and Tuktoyaktuk, replacing them with CARS facilities. Of the remaining 11 FSS, 5 (Cambridge Bay,²³ Yellowknife, Fort Simpson, Fort Smith, and Hay River) had been identified as candidates for closure in 1994. The FSS slated to remain in service were retained for "safety and special considerations". Traffic at the Mackenzie valley sites slated for retention in 1994 had dropped marginally since then.

The LOS also ignored the existence of CARS. While the NAV CANADA-operated facilities were mentioned in the policy, no reference was made to CARS. The 32 CARS operated by the GNWT greatly outnumbered the FSS, and only Yellowknife is served by a tower. CARS is, arguably, the standard level of service in the north. NAV CANADA indicated that the reason for this was that CARS were established on criteria which were not activity-based. There were also a number of legal issues involved.

²¹ The policy is actually more complex, recognizing unique characteristics such as traffic complexity and the mix of commercial and non-commercial traffic. While the activity criteria were occasionally applied rigidly under Transport Canada, NAV CANADA uses these as the basis for initiating Aeronautical Studies (see section 2.5).

²² Statistics Canada. 1996. Aircraft Movement Statistics. Annual Report.

²³ Cambridge Bay FSS was closed in 1995 and replaced by a CARS.

2.4 GNWT Reaction and NAV CANADA Response

The difference in treatment of the CARS program extends beyond the fact that it is delivered by the territorial governments, rather than by NAV CANADA itself. Some NAV CANADA personnel openly resented the fact that the Corporation had been saddled with the northern airspace, and felt that some CARS existed more for the purposes of job creation in their communities, than to serve any operational requirement. Certainly, the evolution of the CARS program had involved some social development motivations on the part of the GNWT.

CARS had, however, been activity-based, though not in the sense that NAV CANADA uses the term. CARS was originally conceived as a means of delivering the basic support necessary for flight planning and the conduct of an instrument approach. They were located at “Arctic B & C” airports, which had, in turn, been established at communities which had stable populations of 100 or more and scheduled air service.

Some stakeholders felt that by denying that CARS represented a level of service, the Corporation made its own future requirements less stringent. If there was no CARS LOS, then it followed that modifications in the delivery of CARS services were a purely operational decision on the part of the Corporation, and would not require broad public consultation. CARS would be argued to be merely the sum of its parts; and were any part (such as weather observations) no longer required, or available more cheaply in some alternate form of delivery, then this could be implemented with little difficulty. An earlier attempt by Transport Canada to replace manned weather stations with automated sensors (AWOS) had failed because of technical shortcomings of the devices. A moratorium was in place on AWOS deployment but, despite repeated assurances by NAV CANADA, stakeholders were very sensitive about the safety implications of loss of human weather observers.

NAV CANADA tended to view its provision of services at the northern and remote sites as a responsibility mandated by the Act, rather than a part of its core service. The CARS program is one viable method of meeting its commitments. Alternate options, such as weather observations through private contractors, or the carriers themselves, need to be explored. If the deficiencies of AWOS could be corrected, and this demonstrated to the satisfaction of users, AWOS might again be a viable option in some cases. Further, there had never been a comprehensive review of the services needed, and how best the resources of the ANS should be deployed to meet these requirements.

The public consultations required by the Act were met by publishing the proposed LOS on the Corporation’s web site in September. NAV CANADA had presented its initial draft policy to NATA in June, but were unable to present the final draft to NATA and the GNWT before late October, at which time it argued that it was too late for amendments, since the policy had to be published by the end of the month to meet the statutory requirement. The GNWT and NATA responded with letters indicating that they believed that CARS represented a *de facto* level of service.

The issue of CARS LOS may have been addressed by the Corporation in public statements that it would not change a level of service, or *the manner of delivery* of a service, without an

Aeronautical Study. It has also publicly stated that it will not deploy AWOS, even if the moratorium is lifted, without consultations with its customers.

2.5 Aeronautical Study: The Q850 Risk Management Process

The final major provision of the Act was a prescription for broad public consultation when the Corporation wished to change a LOS. While the Act required this only for reductions in the LOS (C-20: 18), NAV CANADA has indicated that the process which it will use for reductions will be applied for all proposed changes, including the commissioning of new sites, increases in the LOS, or changes in means of delivery.

The Aeronautical Study is an application of a Canadian Standards Association risk management model. The Q850 model includes a process for identification of safety and economic risks, public consultation, and mitigation of risks considered significant by stakeholders. It was developed by incorporating some of the best practices in international risk management.

A study is divided conceptually into six phases which aim to identify needs issues and concerns of stakeholders (broadly defined), evaluate the risk associated with change in service, identify the mitigation strategies which may address these issues, and control and monitor the changes. These phases may be repeated where more information or analysis is required, and the process aims to achieve a high degree of communication with stakeholders.

2.6 Fort Simpson Aeronautical Study

Fort Simpson was not the first use of the Aeronautical Study in the NWT. The process had been used to justify the reduction of hours of operation at Fort Resolution CARS the previous year. This LOS change did not represent much of a challenge, since it was conceded by GNWT that the additional hours were not required by the air carriers.

The Fort Simpson proposal seemed rather innocuous on the surface. NAV CANADA wished to remove the midnight shift at the FSS so that it could bolster staffing at another station. The study ran into difficulties almost immediately, however, because economic interests in the community were angered at the potential loss of a person-year of salary. The community had lost a considerable number of jobs in the previous year as the result of a GNWT austerity program, and merchants and politicians were sensitive to any reduction in spending in the community. Any perceived service reduction to the community would also, it was argued, make it more difficult to attract investment.

NAV CANADA has no mandate to subsidize local economies, and was likely prepared to weather the storm on the service reduction, however unexpected difficulties were raised in the consultation process. These were identified first by Arctic Airports (GNWT), and later by the carriers. The first was that the maintenance of the airfield is compromised if there is no 24-hour presence. Fort Simpson has a paved runway, and in the event of freezing rain, urea must be applied within the first half hour to be effective as an anti-icer. If ice is allowed to form, it

may be many days before the runway is fully serviceable. FSS and the GNWT had a protocol that the specialists would notify the airport manager immediately of freezing precipitation during “the quiet hours”. Since the airport is some distance from the town, some arrangement would have to be made to avoid “losing the runway” to freezing rain. The maintenance of the runway is the GNWT’s responsibility as airport operator, but there are both cost and safety implications to the stakeholders.

There would also need to be a protocol established for medevacs. The nearest airfield in 24-hour operation is Hay River, but it is too distant for its altimeter to be used for an instrument (IFR) approach. IFR medevacs would require a weather observation and current altimeter setting before departure from Yellowknife.

The most surprising finding, however, was almost unrelated to operations at Fort Simpson. While the station traffic on the midnight shift is low, it remains in use as an IFR alternate, especially for the busiest station in the north, Yellowknife. Hay River, located on Great Slave Lake, is closer to Yellowknife and has an instrument landing system. What it lacks, and Fort Simpson has, is commercially available jet fuel. While some carriers maintain their own bowsers at the airport, there is no guarantee that fuel will be available for other carriers. For that reason, Fort Simpson, 200 nautical miles distant from Yellowknife, is the preferred flight plan alternate. No pilot is likely to divert to an alternate where there is no fuel supply for the aircraft.

The operational effect of the reduction in hours was that no weather observations would be available to support a terminal forecast (TAF). While an Area Forecast can be used for an IFR alternate, the legal approach minima are considerably higher than they are with a TAF. Without 24 hour weather observations to support a TAF, Fort Simpson would be available as an alternate less often. This, carrier representatives argued, implied significant increases in fuel uplift for IFR aircraft, which presented an unacceptable financial burden on the operators. Pilots suggested that it would reduce safety by increasing the pressure on the captain to land in Yellowknife, regardless of the weather conditions.

2.7 The “North of 60” Aeronautical Study

The Fort Simpson process reinforced the point made by many experienced “Arctic hands”, both inside and outside the Corporation. The north, because of its limited infrastructure must be viewed as a system, rather than as a collection of parts. A piecemeal approach tends to the conclusion that most of the sites do not require their current level of service. When viewed as elements of a system, however, the importance of the web of services across the vast and inhospitable territory becomes more understandable. The consultative process of the Aeronautical Study was successful in identifying this issue.

Successful consultation, however, did not solve NAV CANADA’s problems. The long expected rationalization of services had reduced its long run training requirements, and management had reacted accordingly. In the short run, however, delay in implementing the program had left NAV CANADA with a severe staff shortage. As well, the Corporation was

expected by its stakeholders to reduce costs.²⁴ There was clearly a need to reduce services in some areas, and perhaps to redeploy resources to better meet user requirements. Carrier representatives at the Fort Simpson consultations, for example, had used the occasion to press the case for increased hours of operation at Cambridge Bay, the hub of the central Arctic. This had been outside the scope the Fort Simpson study.

Before the Fort Simpson Aeronautical Study was concluded, NAV CANADA changed its approach. At the fall Airline Consultative Committee (ACC) meeting, NAV CANADA announced a comprehensive approach to ANS services in the north, which would be conducted as a single Aeronautical Study of massive proportions. The Fort Simpson study, as well as a similar study on Resolute Bay FSS, would be rolled into the larger study, though some decisions on these particular sites would be made as early as possible, for operational reasons.

The Terms of Reference (TOR), dated 24 September, was presented to NATA and the GNWT on 20 October.²⁵ The study would encompass Yukon and Northwest Territories, but would exclude northern Quebec, which had its own distinct operating features. Sites in the northern sections of the prairie provinces might be examined as parts of the “system”, where these were discovered to affect northern operators, but would not fall within the scope of the study itself.

The Aeronautical Study Team would include two members of government of the NWT and one from Yukon, a member from the Northern Air Transport Association, as well as members of the Safety and Service Design (S&SD), Air Traffic Services, and Technical Services divisions of NAV CANADA’s western and central regions, and an S&SD representative from its Quebec region. Subsequently, First Air was approached to place a member on the team. Based just outside Ottawa, and therefore convenient to NAV CANADA’s head office, First Air also had the potential to devote management resources to the project which the smaller northern operators would not have been able to afford.

The study team would be supported by a risk management team with head office and regional NAV CANADA representation. This group would be responsible for research and the generation of cost-benefit analyses using complex economic modeling software, and for the development of risk mitigation strategies for issues raised in the Aeronautical Study Team’s public consultations.

²⁴ In September 1997, the Corporation expressed its intention to reduce costs by \$135 million by the year 2000. This was to be accomplished largely through the reduction of management and administrative overhead (*Shaping Our Future: 1997-2000 Statement of Corporate Direction: overview*).

²⁵ NAV CANADA 1997 *Aeronautical Study Terms of Reference, Airport Advisory and Flight Information Services Provided in Northern and Remote Areas*. Some of the following details were added on the basis of comments made at the initial consultation meeting with NATA on 20 October, 1997.

The initial consultations to identify "needs, issues and concerns" took place in December of 1997. The "North of 60" study is expected to be completed in the third quarter of 1998.

3.0 CONCLUSIONS

The unique problems facing aviation in the northern and remote areas of Canada were addressed in the legislation which transferred control of the ANS to NAV CANADA. The drafters of the legislation were faced with a need to ensure the viability of air transportation, while allowing NAV CANADA the flexibility to conduct its business in a commercial fashion.

The transition from a ticket tax to a user fee based on aircraft weight impacted the north disproportionately because of the operational characteristics of northern aviation, and has indirect effects on other non-aviation related systems such as nutritional subsidy programs. While consumer costs may actually decline as a result of transition in the south, the fragile northern economy will see increases. The initial impact will be felt in March 1998, with a second impact of similar magnitude in November 1998. These increases will compound already high transportation costs. As rationalization takes place in future years, northern users will benefit from any cost reductions at the same rate as southern users.

Services provided may well decrease at the same time as costs increase. Two separate processes are at work, and the pricing of services is outside the scope of the team which is responsible for the Aeronautical Study. Users, and the consumers they serve, see these issues as related. NAV CANADA will have to communicate its views well to overcome stakeholder resistance. Initial overstatement of impacts by carriers may have made this a issue more difficult, but both NAV CANADA and the carriers have worked constructively to ascertain the true impacts.

It will be difficult for users to make informed decisions on the services which are required, when the costs of the options are not known. While the basic tenet that safety must not be compromised is held by all parties, site specific fees are not ruled out. The temporary exemption of CARS from phase one fees was a concession to northern carriers, but it makes choosing the appropriate level of service more difficult where FSS closures and other service options are being considered.

The technical nature of the issues at hand makes it difficult for consumers, who ultimately pay for the system through ticket prices, to take a meaningful part in the discussion. Communities have concerns about employment and development which are legitimate, but are not within the mandate of NAV CANADA. The involvement of the territorial government is therefore very important. Arctic Airports also operates the airports in the NWT, and manages the CARS program, so determining the public interest is a complex task.

The ANS Act provides the territorial Minister of Transportation with a mechanism to elevate any NAV CANADA reduction in service to the level of the federal Minister of Transport for a decision. The political level may not be the most favorable forum for NAV CANADA. It is

therefore in its interest to make the best use of the Aeronautical Study process, and to achieve some degree of agreement among the affected users and communities.

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**THE OPTIMIZATION PROBLEM FORMULATION AND ALGORITHM OF
ELIMINATING FLIGHT COLLISIONS**

1/4

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1. THE INPUT DATA FOR THE OPTIMIZATION PROBLEM

Let us assume that index i appears in set I , where $I = \{1, \dots, i, \dots, I\}$, where I is the number of all flight direction change points on a given territory.

It is assumed that index l appears in set L , where $L = \{1, \dots, l, \dots, L\}$, where L is the number of aerodromes/DCPs located on a given territory.

Let us assume that the air traffic over a given territory takes place within corridors determined by the flight corridor axis, i.e. by the lines 'connecting' individual points of space over the direction change points.

It is assumed that each flight direction change point is assigned a set of numbers of flight direction change points directly adjacent (contiguous) to it. Let $I(i)$ be a subset of set I for each $i \in I$, i.e., let $I(i) \subseteq I$. Each pair (i, i') such that with i -th number of flight direction change point given, number $i' \in I(i)$, which means that the i' -th flight direction change point is adjacent to the i -th flight direction change point. It is assumed that for each $i \in I$ flight direction change point there is given set $I(i)$.

In a given corridor spreading between two adjacent flight direction change points, aircraft flights may take place at different flight levels.

Let us assume that for each pair of adjacent flight direction change points (i, i') where $i \in I$, $i' \in I(i)$ there is given set $P(i, i')$ of the numbers of all flight levels on which there may take place aircraft flight between two adjacent flight direction change points.

Let P be a set of all flight levels. Flight levels are numbered by means of variable p . Therefore, we assume that $p \in P$ and that $P = \{1, \dots, p, \dots, P\}$.

It is also assumed that $P(i, i') \subseteq P$. In exceptional cases the following may be true: $P(i, i') = P$, which indicates that air traffic between flight direction change points of numbers i and i' may be distributed with flexibility.

It is assumed that the change of aircraft flight level or its take-off would be caused by the necessity to avoid collision with another aircraft. Such a collision may be avoided in a given corridor by changing either the aircraft's flight level or its take-off moment, providing the change is admissible (possible), meaning that the level the aircraft is directed towards is not occupied by another aircraft, or - in the case of take-off moment change, the altered moments of flights over each DCP retain the separation times determined for those DCP. Simultaneously, in case of flights in the same direction, the beginning of the time interval when the section between adjacent DCPs is occupied by an aircraft must, for the sake of safety, be shifted in time in respect to the beginning of the moment when this section is to be occupied by other aircraft. If aircraft fly over the same section between adjacent DCPs, but in opposite directions, the moment of entering a section by the currently co-ordinated aircraft must be delayed for at least the length of separation time obligatory in this section, in regard to the moment when previously co-ordinated aircraft had left this section.

It is assumed that air traffic is planned and realised in thus determined flight corridors. For every flight of every aircraft the following factors are known: aerodrome of departure, desired take-off moment and the moments of reaching all flight direction change points characterising a given route, as well as the desired flight levels between adjacent DCPs, and the landing moment at the aerodrome of destination. For each aircraft there is also known the cost caused by (forced) change of flight level or of change of the moment of take-off from the aerodrome of departure.

Therefore, it is assumed that there is given mapping σ , which maps Cartesian product $S \times P$ into a set of real positive numbers R_+ , i.e.:

$\sigma: S \times P \longrightarrow R_+$, where quantity $\sigma(s,p) \in R_+$, is interpreted as the cost of an s-th aircraft on p-th flight level.

Let S be a set of numbers of aircraft that are to perform flights over a given territory. It is assumed that each aircraft will be numbered by means of variable s so that set S of the numbers of aircraft has the following form: $S = \{1, \dots, s, \dots, S\}$, where S is the number of all aircraft.

It is assumed that the route of an s-th aircraft taking off from an l-th aerodrome is presented in the form of vector $w(s,l)$ of components interpreted as follows:

- $w(1,s,l) = i_0$ the number of the aerodrome of departure ($i_0 = l_0$) of an s-th aircraft;
- $w(2,s,l) = p_1$ the number of the flight's level (the number of the 'first' flight level for a given route), on which the s-th aircraft taking off from aerodrome l_0 ought to be found;
- $w(3,s,l) = i_1$ the number of the flight direction change point (the number of the 'first' flight direction change point for a given route), over which the aircraft ought to change flight direction;
- ...
- $w(n,s,l) = i_n$ the number of the flight direction change point (the number of the n-th flight direction change point for a given route), over which an s-th aircraft ought to change flight direction;
- $w(n+1,s,l) = p_n$ the number of flight level over which an s-th aircraft ought to be found between flight direction change points i_n and i_{n+1} ;
- $w(n+2,s,l) = i_{n+1}$ the number of the flight direction change point (the number of n+1-st flight direction change point for a given route), over which an s-th aircraft ought to change flight direction;
- ...
- $w(N(s,l),s,l) = i_{N(s)}$ the number of the aerodrome of destination (landing; $i_{N(s)} = l_k$) for an s-th aircraft.

As a result the route of an s-th aircraft, taking off from an l-th aerodrome is characterised by means of vector $w(s,l)$ as:

$$w(s,l) = \langle w(1,s,l), w(2,s,l), w(3,s,l), \dots, w(n,s,l), w(n+1,s,l), w(n+2,s,l), \dots, w(N(s,l),s,l) \rangle$$

where $N(s,l)$ is the number of components of vector $w(s,l)$, and each vector is interpreted as above.

Flight planning for each aircraft consists in determining - for a given sequence of numbers of flight direction change points (that constitute the aircraft's route) - the number of flight level (not necessarily consistent with that determined by the person placing the flight order) between adjacent flight direction change points whose covering in a given sequence enables the aircraft to reach the aerodrome of destination.

Moreover, for each flight route there will be determined the moment of aircraft take-off, taking into account the existing traffic situation, i.e. there will be determined such a moment of aircraft take-off that enables non-collision flight along the route and, consequently, non-collision arrival at the aerodrome of destination.

It results from the above that the "cheapest" route, from the point of view of the costs of flight from the aerodrome of departure to the aerodrome of destination, is the route the aircraft actually covered on its way to its destination. For a given traffic situation there may arise the necessity to choose another, 'worse' from the point of view of the costs of flight, route of aircraft flight. It is assumed that the cost of aircraft flight according to route depends on what level between adjacent flight direction change points the aircraft flies on. It is assumed that the cheapest is flight taking place on the levels determined by

the person placing the flight order. Every change of flight level, caused by an existing traffic situation between any adjacent flight direction change points, increases the costs of aircraft flight.

Operative flight route planning is performed assuming the existence of a time horizon. The duration of the horizon (the horizon's granulation) is conditioned by 'constancy' during the traffic situation. It is assumed that the duration of a given, "constant" traffic situation is a multiplicity of a given constant quantity that constitutes the length of the adopted time horizon.

A term of temporal constancy of a given traffic situation is used for "normalising" flight level changes. It is assumed that time distances between flight direction change points are large enough. An aircraft covering this distance may simultaneously perform many manoeuvres (e.g. change its flight level in order to overtake another aircraft or in order to let an aircraft flying in the opposite direction, pass). It is thus conventionally assumed that the time distance between existing adjacent flight direction change points is divided into a number of smaller time intervals. A constant temporal length of an interval is connected with an aircraft's 'temporal capacity' to change its flight level. This means that the constant temporal length is determined by that time interval length which is necessary for the aircraft to perform the manoeuvre of flight level change. Thus in practice it is impossible for an aircraft to change its flight level during two (or more) lengths of time intervals. After it has changed its flight level, an aircraft may continue its flight on the new level for many time intervals, until there is a new decision situation, determining a new type of manoeuvre to be performed by the aircraft. It is thus assumed that between existing adjacent flight direction change points "additional" flight direction/flight level change points are added. The result is the division of flight time into shorter intervals of length determined on the basis of an earlier assignation.

The result of previously adopted assumptions is the fact that vector $w(s,l)$ describing the flight route of an s -th aircraft taking off from an l -th aerodrome, consists of a greater number of components. The number is increased because of an arbitrary division of the time interval between existing adjacent flight direction change points, while the interpretation of the components remains the same.

The essence of planning each aircraft's flight will also be changed. As previously, it consists in determining, for a given sequence of flight direction change points (constituting the aircraft's flight route), flight levels (not necessarily identical with those determined by the person placing the flight order) between the flight direction change points, whose covering in a given sequence allows the aircraft to reach the aerodrome of destination. Similarly, for each flight route, there will be determined the aircraft take-off moment taking into account the existing traffic situation, i.e. such an aircraft take-off moment that allows a non-collision flight along the aircraft's route and, consequently, free from collision arrival of the aircraft at the aerodrome of destination.

2. THE DECISION VARIABLES OF THE OPTIMIZATION PROBLEM

Let us introduce the following decision variable:

$$x(w(n, s, l), p, w(n + 2, s, l)),$$

of its value equal zero or one.

If: $x(w(n,s,l),p,w(n+2,s,l))=1$, then an s -th aircraft, taking off from an l -th aerodrome is on p level, between flight direction change points of numbers determined by the numerical value of quantity $w(n,s,l)$, and by the numerical value of quantity $w(n+2,s,l)$.

Otherwise, i.e. when $x(w(n,s,l),p,w(n+2,s,l))=0$, then an s -th aircraft, taking off from an l -th aerodrome, is not on the level determined by the numerical value of quantity p , between flight direction change points of numbers determined by the numerical value of quantity $w(n,s,l)$ and by the numerical value of quantity $w(n+2,s,l)$.
Let us define the following decision variable:

$$t(w(n,s,l),p,w(n+2,s,l)),$$

adopting its values from within a set of real positive numbers, i.e.:

$$t(w(n,s,l),p,w(n+2,s,l)) \in \mathbb{R}^+$$

The decision variable:

$$t(w(n,s,l),p,w(n+2,s,l)),$$

is interpreted as the moment when an aircraft taking off from an l -th aerodrome, enters a level determined by the p -th numerical value; the aircraft is between flight direction change points defined by numbers determined by the numerical value of quantity $w(n,s,l)$ and by the numerical value of quantity $w(n+2,s,l)$.

3. OPTIMIZATION PROBLEM RESTRICTIONS

The numerical values of decision variables are to be established when the following restrictions are satisfied:

1⁰ - there may be no more than one aircraft on a p -th flight level, contained between selected flight direction change points, for aircraft heading in opposite directions on the same p -th flight level:

$$\sum_{s \in S} [x(w(n,s),p,w(n+2,s)) + x(w(n+2),p,w(n,s))] \leq 1$$

2⁰ - restriction concerning s and s' aircraft entering p -th level, using the same level "in the same direction":

where $\delta(s,s')$ is the value of separation between s and s' aircraft, assuming that the aircraft enter the p -th level in the following sequence: first - s -number aircraft, next - s'

$$t(w(n,s',l),p,w(n+2,s',l)) \geq t(w(n,s,l),p,w(n+2,s,l)) + \delta(s,s')$$

aircraft. The above restriction ought to be apply to every pair of aircraft entering a given flight level and flying on the same level in the same direction;

3⁰ - restriction concerning an s -th aircraft's flight continuity:

$$\sum_{p \in P(w(n,s,1),w(n+2,s,1))} t(w(n,s,1),p,w(n+2,s,1))x(w(n,s,1),p,w(n+2,s,1)) + \tau(w(n,s,1),w(n+2,s,1)) = \sum_{p \in P(w(n+2,s,1),w(n+4,s,1))} t(w(n+2,s,1),p,w(n+4,s,1))x(w(n+2,s,1),p,w(n+4,s,1))$$

where $\tau(w(n,s,1),w(n+2,s,1))$ designates the time needed for an s -th aircraft to cover the distance between the flight direction change points determined by the numerical values of quantities $w(n,s,1)$ and $w(n+2,s,1)$;

4⁰ - restriction concerning an s -th aircraft's selection of flight level between given flight direction change points:

$$\sum_{p \in P(w(n,s,1),w(n+2,s,1))} x(w(n,s,1),p,w(n+2,s,1)) = 1$$

5⁰ - aircraft flying on the same flight level are not allowed to "meet" above a flight direction change point;

$$t(w(n,s,l), p, w(n+2,s,l)) + \tau(w(n,s,l), w(n+2,s,l)) \neq \\ t(w(n',s',l'), p, w(n+2,s',l')) + \tau(w(n',s',l'), w(n+2,s',l'))$$

this restriction ought to apply to every pair s,s' of aircraft that may meet above a flight direction change point of the following number $w(n+2,s,l)=w(n+2,s',l')$, as well as to each flight direction change point over which aircraft might meet;

6⁰ - restriction concerning the selection of an s-th aircraft's take off moment from an l-th aerodrome:

$$T^*(s,l) \leq t(w(1,s,l), p, w(3,s,l)) \leq T^{**}(s,l)$$

where $T^*(s,l)$, $T^{**}(s,l)$ designates the earliest and the latest moment, when an s-th aircraft may take off from an l-th aerodrome (prescribed quantities);

7⁰ - when given: earliest and latest take-off moment for aircraft taking off from an l-th aerodrome are not disjoint intervals, each aircraft's selection of the take-off moment ought to simultaneously satisfy the following set of restrictions:

$$T^*(s,l) \leq t(w(1,s,l), p, w(3,s,l)) \leq T^{**}(s,l) \\ t(w(1,s',l'), p, w(3,s',l')) \geq t(w(1,s,l), p, w(3,s,l)) + \delta(s,s')$$

when aircraft take off from an l-th aerodrome in the following sequence: first s-number aircraft, then s' aircraft;

8⁰ - the formal restriction concerning the numerical values of decision variables has the following form:

$$x(w(n,s,l), p, w(n+2,s,l)) \in \{0,1\}, \quad t(w(n,s,l), p, w(n+2,s,l)) \in R +$$

4. THE CRITERION FUNCTION OF THE OPTIMIZATION PROBLEM

The criterion function comprises the total cost of all aircraft flights taking place in a given area. The cost is to be minimised.

Let us assume the following form of the criterion function:

$$\sum_{s=1}^S \sum_{l=1}^L \sum_{n=1}^{N(s,l)} \sum_{p \in P(w(n,s,l), p, w(n+2,s,l))} x(w(n,s,l), p, w(n+2,s,l)) \sigma(s,p)$$

The search for optimum, in the sense specified above, solution is to be performed only when all restrictions ensuring flight schedules free from collision are satisfied.

5. THE METHOD OF SOLVING THE OPTIMIZATION PROBLEM

5.1. The construction of a flight graph

The suggested method of solving the optimization problem is based on a flight graph illustrating flight schedules submitted for co-ordination.

The first step while generating the above mentioned graph is to define its nodes. In the suggested method graph nodes correspond to the ordinal indexes of aerodromes declared in the flight area, as well as flight direction change points.

The second step consists in generating flight graph arcs, representing the connections between adjacent aerodromes and/or flight direction change points resulting directly from the submitted flight plans.

The third and last step of generating a flight graph is to replace graph arcs with new nodes, while the indexes describing the new nodes are not changed in relation to the arcs they were generated from. Thus a flight graph is generated with the connections between neighbouring aerodromes and/or flight direction change points are "reduced" to the form of a graph node.

The analysis of non-collision aircraft flight co-ordination on the basis of the above graph form is restricted to surveying and removing conflicts only in the graph nodes.

5.2. The rule of selecting a priority flight schedule

The rule of selection concerns designating the first, undisturbed flight plan serving as the standard, in comparison to which other flights would be tested from the point of view of their being free from the possibility of collision. In this way every new plan would be co-ordinated with already generated flight plans.

5.3. The mechanism of making flights free from the possibility of collision

The key procedure of the main program - *Plan Co-ordination*, verifies the temporal moments of occupying stable, ground elements of flight area (or the moments of flying over them), as well as the time intervals of occupying air connections, by surveying submitted and correctly arranged flight plans, from the point of view of indexes pointing to specific flight area elements, repeated in various flight plans.

The legend to the block diagram:

P - number of aerodromes/DCPs in a given flight area,

p_j - presently analysed aerodrome/DCP,

S - number of aircraft operating in a given flight area,

s_i - presently analysed aircraft,

t_0 - take-off moment of an I-th aircraft (I-th flight plan),

t_j - temporal moment of an air event (presence) of an aircraft over an j-th aerodrome/DCP,

p_{i+n} - consecutive aerodrome/DCP along the flight route of an i-th aircraft,

s_{n+1} - consecutive flight plan (aircraft) according to flight graph load,

O_{pj} - total value of j-th aerodrome/DCP load by all aircraft (concerns the number of air events),

O_{ni} -value of flight graph load (network) by an i-th aircraft (flight plan).

t_{sep} - separation time suggested for currently analysed element of flight area (aerodrome/DCP or air corridor).

5.4. The block diagram of an algorithm of ensuring non-collision of flights

5.5. Computer implementation of an algorithm of ensuring flights free from collision

5.5.1. Input data form

The executive program uses the following input data:

a) **aerodrome/DCP** data specifying:

- aerodrome/DCP number,
- aerodrome/DCP parameters, such as:
 - aerodrome/DCP availability (logical variable),
 - separation time between air events,

b) **flight area** data specifying:

- possible air connections between suggested aerodromes/DCPs,
- the availability of air connections between suggested aerodromes/DCPs,
- separation time between air events operative for a given air connection between suggested aerodromes/DCPs,

c) **flight plans** (introductory) specifying:

- aircraft flight route submitted for co-ordination, particularly taking into account:
 - the numbers of aerodromes/DCPs suggested for a given flight area,
 - assumed time moments (hours, minutes) of aircraft flights over subsequent aerodromes or flight direction change points (DCP) located along the flight route. This concerns every individual aircraft.

The form of input data has been defined globally (for all data types) as two-dimensional record tables. Depending on whether the description concerns area data or flight plans, records indexed by means of the above mentioned tables may consist of 5 (in the first case) or 2 (in the second case) areas.

Source code notations are as follows:

```
type // Tablica Planów Lotu
    Times = packed record
        DCP : integer;
        moment: integer;
    end;
    TTimes = array[1..MaxS,1..MaxL] of Times;

type // Obszar lotów (pierwotny)
    Dane = packed record
        link : string[1];
        nazwa_lot : string[20];
        TSep : integer;
        new_DCP : integer;
        dir : string[2];
    end;
    TDane = array[1..MaxL,1..MaxL] of Dane;
```

Some of the areas of the record describing area data are suggested together with the first referral to them and then re-suggested automatically by the program depending on what component has been selected by the user (using the mouse). Any edition of records corresponding to input data, stored in the computer's memory, ought to be concluded with pressing the right button - usually 'Apply'. The use of the button initiates an internal

For submitted flight plans there are defined load indexes– essential for determining flight plan priorities. For each flight area element (aerodrome/DCP, the connections between neighbouring aerodromes/DCPs) the load index defines: how many times a flight area element is mentioned in the description of all submitted for co-ordination flight plans. A flight plan load index is the total sum of those flight area element loads that appear in the description of the flight route.

Flight plan number	Flight plan load index
1	7
2	8
3	4

Table 2

A new sequence of flight plans (conflict situations have been highlighted):

Flight Plans 2	Area elements - index	5	6	3	2	4
	Separation time	10 min				
1	Entry moment	09:40	10:25	11:10	12:05	12:45
	Area elements - index	1	2	3	5	
3	Separation time	10 min	10 min	10 min	10 min	
	Entry moment	10:20	11:30	12:30	13:20	
3	Area elements - index	1	2	4		
	Separation time	10 min	10 min	10 min		
3	Entry moment	11:10	12:10	12:50		

Table 3

The methods of determining the take-off moment delay for a co-ordinated aircraft:

$$t_{s_mov} = t_{pp} - t_p + t_{sep} \quad (1)$$

$$t_{s_mov} = t_{kp} - t_p + t_{sep} \quad (2)$$

where:

t_{pp} – initial moment when an aircraft performing a flight plan of higher priority in comparison to the previously co-ordinated flight plan (lower priority), enters an area element,

t_{kp} – moment when an area element is left by an aircraft performing a flight according to a higher priority plan in comparison with the flight plan currently co-ordinated (lower priority),

t_p – initial moment when a currently co-ordinated aircraft enters an area element,

t_{sep} – separation time between air events suggested for a given flight area element.

(1) – used for eliminating collision situations (between aircraft) located:

- a) over aerodromes/DCPs,
- b) within air connections between adjacent aerodromes/DCPs, for aircraft heading in the same direction,

- c) (2) - used for eliminating collision situations (between aircraft) located within air connections between adjacent aerodromes/DCPs, for aircraft heading in opposite directions.

The take-off moment of plan number 1 – according to formula (2), is to be shifted by 45 min.

Flight Plans	Area elements - index	5	6	3	2	4
	Separation time	10 min				
2	Entry moment	09:40	10:25	11:10	12:05	12:45
1	Area elements - index	1	2	3	5	
	Separation time	10 min	10 min	10 min	10 min	
	Entry moment	11:05	12:15	13:15	14:05	
3	Area elements - index	1	2	4		
	Separation time	10 min	10 min	10 min		
	Entry moment	11:10	12:10	12:50		

Table 4

The take-off moment of plan number 3 – according to formula (1), is to be shifted by 5 min.

Flight Plans	Area elements - index	5	6	3	2	4
	Separation time	10 min				
2	Entry moment	09:40	10:25	11:10	12:05	12:45
1	Area elements - index	1	2	3	5	
	Separation time	10 min	10 min	10 min	10 min	
	Entry moment	11:05	12:15	13:15	14:05	
3	Area elements - index	1	2	4		
	Separation time	10 min	10 min	10 min		
	Entry moment	11:15	12:15	12:55		

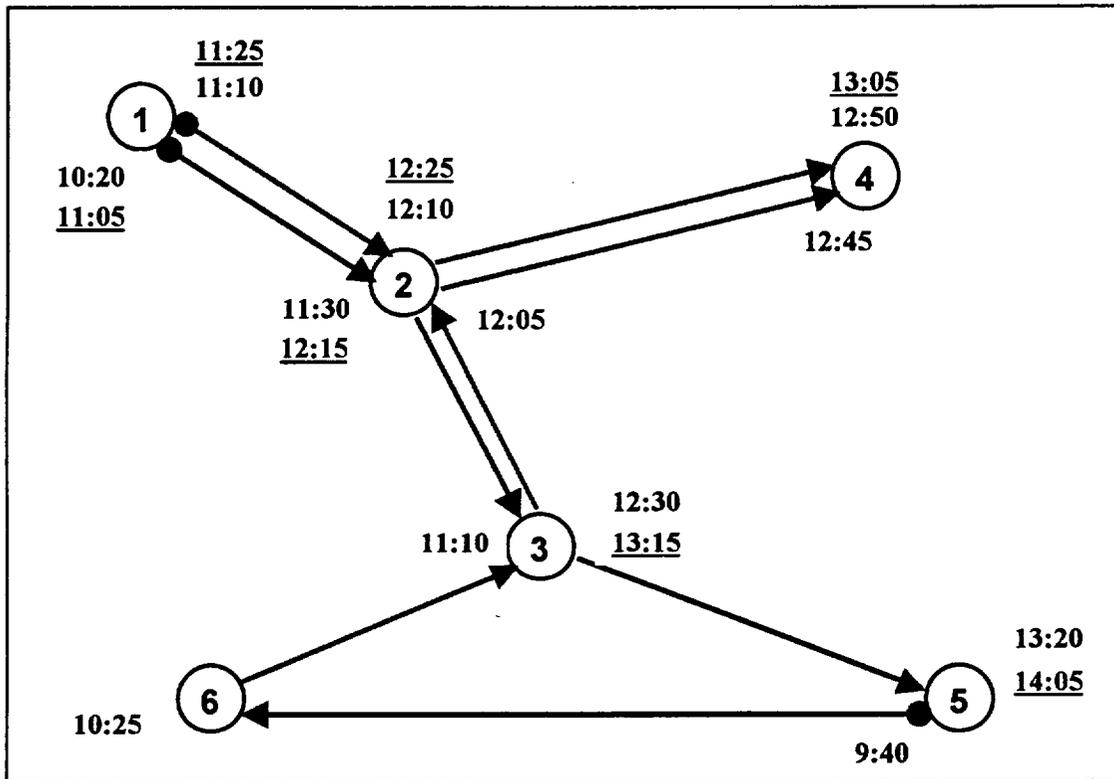
Table 5

The take-off moment of plan number 3 – according to formula (1), is to be shifted by 10 min.

Flight Plans	Area elements - index	5	6	3	2	4
	Separation time	10 min				
2	Entry moment	09:40	10:25	11:10	12:05	12:45
1	Area elements - index	1	2	3	5	
	Separation time	10 min	10 min	10 min	10 min	
	Entry moment	11:05	12:15	13:15	14:05	
3	Area elements - index	1	2	4		
	Separation time	10 min	10 min	10 min		
	Entry moment	11:25	12:25	13:05		

Table 6 (The result: co-ordinated flight plans)

Illustration of co-ordinated flight plans:



6. CONCLUSIONS

1. Algorithm was created in DELPHI environment, version 3.0.
2. Suggested algorithm may be use for any set of fligth plans.
3. Algorithm is limited by available PC's memory for data storage/input.
4. Results achived so far has taken a direct impact for continue and improvment of presented algorithm.

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The study of aircraft trajectory on airport surfaces

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1. GENERAL CHARACTERISTICS OF MOVEMENT

The study of aircraft movement in a curve is particularly complex. In fact, the main landing gear not having a differential, the aircraft approaching the curve occurs with a series of characteristic drags in the driven wheel.

The aircraft, on having entered the curve at the connecting points between the runway and the taxi path, it follows the guide line, which is traced on the surface, with the nose-wheel following the entry and exit paths. These paths are based on straight traits, on circular, polycentric or clotohydrical type curves.

Yet, while the nose-wheel follows the trajectory, the main landing gear has a different path which takes the wheel or the entire group of back wheels to follow an inside curve towards the margin of the paved surface, reducing the safety especially during high speed.

Therefore, the problem of studying a geometry of exit paths has occurred so that the security of the aircraft trajectory increases, and at the same time the traffic capacity of the runway can increase.

2. THE MANOEUVRE OF AN AIRCRAFT IN A CURVE

The distance between the external principal landing wheel and the margin of the runway must conform to the minimum requirements set out by the I.C.A.O. The conformity to such requirements requires the creation of enlargement strips at the intersections between the taxiway and the runway.

The possible manoeuvre methods of an aircraft, so that it can face such a curve are as follows: -

a) to follow a central line on the runway with the nose wheel, while the wheels of the main landing gear delineate a trajectory nearing that of the margins of the same runway.

b) to follow a mixtilinear guideline external to the central line while the entire main landing gear remains on axis to the same line.

The b) method could be advantageous because it seems to be the most economical solution as it eliminates the necessity to build extension strips. But all in all, the advantages are not as good as they seem. In fact, we must separate the guidelines for every type of aircraft for both directions of circulation. Such solution therefore, becomes impractical due to the multiple lines that would be on the surface of the runway. In particular, at night time or during scarce visibility it would be extremely difficult for an aircraft to follow the correct guide line. Thus it is preferable to adopt the turning method a) as it permits tracing only one guideline on the surface which would be followed by all aircraft, and the strips of extension would be based on that of the largest aircraft considered capable of using the curve.

The first step in designing extension strips is to determine the theoretical trajectory of the centre of the main landing gear. Two different techniques exist [2], below there is one technique briefly explained based on a mathematical model developed by the I.C.A.O.

A few fundamental definitions are reported so that the problem can be examined more closely.

Terms relative to the aircraft.

- *Aircraft reference point "S"*. It is the ideal point on the longitudinal axis of the aircraft that follows the guideline of the traced surface signals, and is positioned vertical to the cockpit.
- *Pivot. "P"* point, the centre of instant rotation.
- *Theoretical axis of the main landing gear*. It is perpendicular to the longitudinal axis of the aircraft, passing through point P.
- *Theoretical length of reference "d"*. It is the distance, which lies between reference point S and the theoretical axis of the main landing gear.

- *Centre of the main landing gear "U"*. It is the intersection point between the longitudinal axis and the theoretical axis of the main landing gear.
- *Carriage way of the main landing gear "T"*. It is the distance, which runs between the external wheels.
- *Guiding angle or visual " β "*. It is the angle formed by the tangent of the guide line S with the longitudinal axis of the aircraft.
- *Steering angle*. It is the angle formed by the longitudinal axis of the aircraft and the direction of the axis of the fore steering landing gear.
- *Guide line*. Trajectory of reference point S, traced on the runway with horizontal signals and/or lights.
- *Centre of guide line "O"*. It is the camber centre of the guide line in its circular part and is the origin of the fixed system of polar co-ordinates.
- *Deviation of the main landing gear " λ "*. It is the distance between the centre of the main landing gear U and the guide line measured perpendicularly to the guide line.

Glossary of symbols.

The following symbols will be used from now on, to describe the trajectory of the centre of the main landing gear and in the planning of the curve extensions.

- d = theoretical reference length of aircraft.
- M = minimum distance existing between the external wheel of the main landing gear and the margin of the paved surface.
- O = camber centre of the guide line.
- P = centre of instant rotation.
- r = radius of the extension strip arch.
- R = bending radius of the guide line of point S.
- S = reference point of aircraft,
- T = track of main landing gear.
- U = centre of main landing gear.
- α = angle between the radial OU and the tangent of the trajectory of point U.
- β = guiding angle.
- λ = deviation of main landing gear.
- ρ, θ = polar co-ordinates of a point (S or U) in the system of polar co-ordinates with origin in O.
- L = width of taxiway.

3. THE TRAJECTORY OF THE MAIN LANDING GEAR IN CASE OF CIRCULAR TURNS

Generally the connections between the taxiways and the runways, with the parking areas and other taxiways, are established by circumference arches and straight traits. The calculation method described below refers to an aircraft in taxiing on a horizontal surface. It is of general validity and allows for sufficient precision to study for extension strips in a curve.

When taxiing the aircraft follows the guide line with the S point, passing from a straight line to a curve. During the course point S continues to follow the trajectory axis of the taxiway, while the main landing gear follows a different course, tending to near the internal margin of the curve with consequent reduction of safety.

Such behaviour on behalf of the aircraft can be more or less accentuated according to the distance of reference, more or less wide, that passes from the centre of the theoretical axis of the main landing gear and point (reference S) situated vertical to the cockpit.

During movement in curve reference point S follows a circumference arch of centre O and radius R. To study the movement of the aircraft it is necessary to have a system of reference co-

ordinates. Both OX and even more ρ and θ_u are the polar co-ordinates of point U . In the entry of the curve the straight line US remains tangent in U in trajectory.

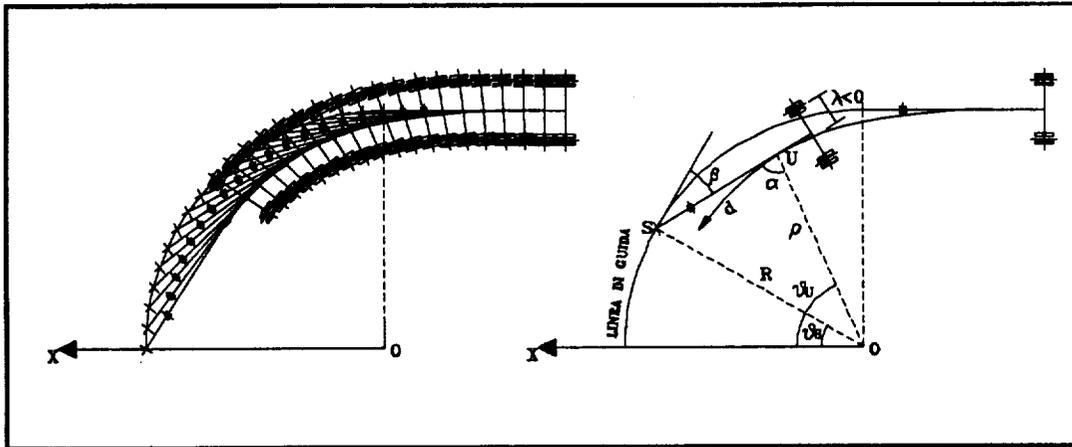


Fig. 1: Explanation of symbols

Under these conditions we obtain the differential equation of the points U :

$$\tan \alpha = \rho \frac{d\theta_u}{d\rho} \quad (1)$$

Expressing ρ as d , R and α we obtain the following differential equation:

$$\rho = d \cdot \cos \alpha \pm \sqrt{d^2 \cdot \cos^2 \alpha - d^2 + R^2} \quad (2)$$

where the positive sign has the value of $\alpha > 90^\circ$ and the negative sign $\alpha < 90^\circ$.

Separating the variables the equation (1) can be written as follows:

$$\frac{d\rho}{\rho} = \frac{d \cdot \sin \alpha \cdot \tan \alpha}{\sqrt{R^2 + d^2(\cos^2 \alpha - 1)}} \cdot d\alpha \quad (3)$$

The solution of the differential equation (3) provides a bi-univocal relationship between θ_u and α for the initial conditions given.

$$\theta_u - \theta_0 = \int_{\alpha_0}^{\alpha} \left(\frac{\sin \alpha \cdot \tan \alpha}{\sqrt{\left(\frac{R}{d}\right)^2 + (\cos^2 \alpha - 1)}} \right) \cdot d\alpha \quad (4)$$

The integration of this expression is simple only in the particular case in which the bending radius R of the guide line is equal to the reference distance d of the aircraft.

In this case, in fact, assuming the initial conditions are $\theta_0 = 0$; $\alpha_0 = 0$ and $p = 2d$ we obtain:

$$\theta_u = \tan \alpha - \alpha \quad (5)$$

with the angles expressed in radians.

The polar angle, which defines the position of the reference point S therefore, has the value

$$\theta_s = \tan \alpha \quad (6)$$

and the corresponding guide angle yields

$$\beta = 2 \cdot \alpha - \pi / 2$$

The deviation of the main landing gear is therefore equal to:

$$\lambda = 2 \cdot d \cdot \cos \alpha - d = d \cdot (2 \cdot \cos \alpha - 1) \quad (7)$$

The general case $R \neq d$ is solved with complex calculations, which does not justify the construction of a fillet or a simple widening of the curve.

In practice, it is convenient to apply to the extension zone the approximate method explained below. The knowledge of guide angle β in all the trajectory points of reference S of the aircraft, allows to construct the points of centre U of the main landing gear and to specify the trajectory of this when veering on the ground.

Supposing, that for small movements of the aeroplane the guide angle β does not change, the centre of instant rotation becomes P point, the so-called "pivot" and not point O. Consequently the aircraft reference point in following the guide line describes a small circumference arch equal to:

$$ds = \frac{R}{d} \times \text{sen } \beta \times d \times \theta_s \quad (8)$$

where d is the theoretical reference length of the aeroplane and R and θ_s the polar co-ordinates of point S with respect to axis OX. We can suppose with approximation, that while reference point S of the aircraft follows the guide line, the variation of guide angle β has the value of

$$d\beta = 1 - \frac{R}{d} \cdot \text{sen } \beta \cdot d \cdot \theta_s \quad (9)$$

therefore establishing a bi-univocal relationship between θ_s and β according to the initial conditions given, in analogy as to what was given before:

$$\theta_s - \theta_o = \frac{d}{d - R \cdot \text{sen } \beta} \cdot d\beta \quad (10)$$

The integration of (10) is obtained considering only the case in which both $R > d$ and presuming furthermore that by:

$$\frac{R}{d} = X \quad K = \sqrt{X^2 - 1}$$

solving (10) for $\beta/2$ and finally introducing the initial conditions $\theta_o = 0$ and $\beta_o = 0$ we obtain after simple passages the following expression of β :

$$\beta = 2 \cdot \arctan \left[\frac{1 - e^{K \cdot \theta}}{X - K - X \cdot e^{K \cdot \theta} - K \cdot e^{K \cdot \theta}} \right] \quad R > d \quad (11)$$

with θ s expressed in radians.

4. THE SWERVE OF THE MAIN LANDING GEAR.

On the carriage way, according to the initial conditions the swerve of U centre of the main landing gear can occur externally or internally to the curve of the guide line traced on the paved surface and follows in sequence reference point S of the aircraft.

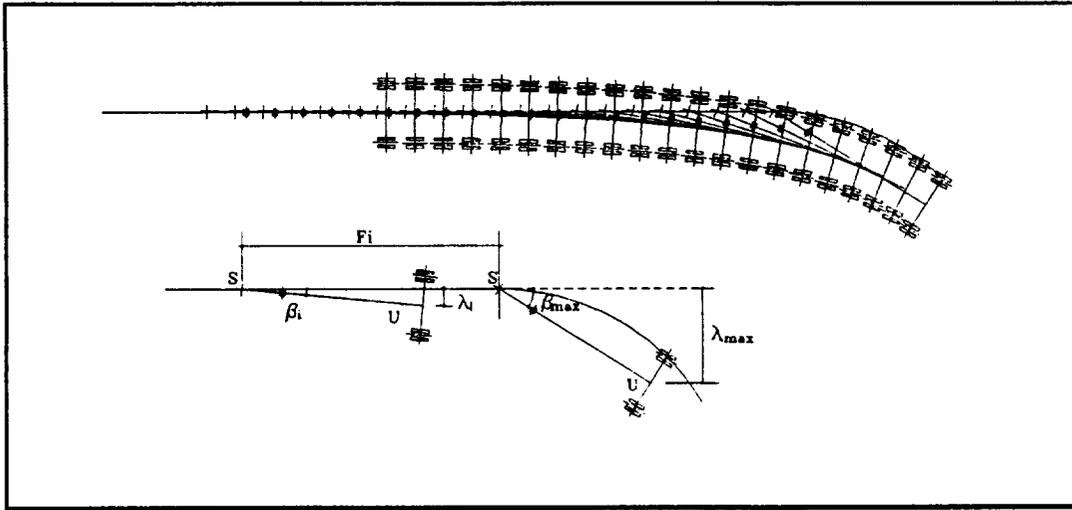


Fig. 2: Explanation of symbols

Along the carriage way or slip path, at the moment in which point S faces the curve, the swerve, initially, of the U centre of the main landing gear is external to the circular curve, and it becomes internal during the completion of the trajectory. With reference to fig. 2 we have the following:

$$USO = \frac{\pi}{2} \pm \beta \quad (12)$$

$$(R + \lambda)^2 = R^2 + d^2 - 2 \cdot d \cdot R \cdot \cos \left(\frac{\pi}{2} \pm \beta \right)$$

The solution of this equation gives the internal and external values of the swerve.

$$\begin{aligned} \lambda_{int} &= \sqrt{R^2 + d^2 - 2 \cdot d \cdot R \cdot \sin \beta} - R \\ \lambda_{est} &= \sqrt{R^2 + d^2 + 2 \cdot d \cdot R \cdot \sin \beta} - R \end{aligned} \quad (13)$$

If we express the swerve values as percentages of the length of the aircraft reference d we obtain, with the previous positions:

$$\frac{\lambda}{d} = \sqrt{1 + X^2 \pm 2 \cdot X \cdot \text{sen } \beta} - X \quad (14)$$

with the sign + or – in the case of external or internal swerve.

At the end of the ground trajectory curve, aircraft reference point S reaches the straight trait of the taxiway before the main landing gear. During this manoeuvre β guide angle diminishes progressively as indicated in fig. 2.

With the previous positions we have:

$$\log \cdot \tan \frac{\beta}{2} = \log \cdot \tan \frac{\beta \max}{2} - \frac{F}{d} \quad (15)$$

the (15) allows calculating the guide angle β so that reference point S of the aircraft follows a distance F on a straight stretch of the carriage way.

$$\beta = 2 \cdot \text{arctan} \cdot \exp \left(\log \cdot \tan \frac{\beta \max}{2} - \frac{F}{d} \right) \quad (16)$$

At the end of a straight trait, the residual swerve of U centre of the main landing gear, assumes the value of:

$$\frac{\lambda}{d} = \text{sen } \beta \quad (17)$$

4. BROADENING IN CURVE.

The geometry of a curve should be that, when the cockpit is positioned on the axis of the taxiway, the safety distance between the external margin of the main landing gear and the limit of the taxiway, should not be less than that specified by the I.C.A.O. rules.

Up to now, it has been possible to know the exact position of point U and consequently also the internal point of the landing gear of the aircraft, in any manoeuvrable sequence in which reference point S follows the guide line consisting of circumference arches and straight tracts. From this knowledge it can, considering the minimum safety margin, determine the internal limit of the fillet. If the taxiway is used in both directions, the calculations must be done for both directions and then the internal envelopment chosen.

Rigorous calculations would be long and useless, as previously explained, and only the utilisation of calculus programmes could make them acceptable. Furthermore, the layout of the slipway likewise obtained could be difficult to execute on the ground. A simple way to face the problem is to follow a fillet built with a circumference concentric arch with a guide line, two tracts, which are the initial and final tracts, and rectilinears which join the edge of the runway at the points and acknowledge the position taken by the aircraft and that they are furthermore tangent to the circular tract.

In these conditions, it is sufficient to calculate the radius r from the central part of the slipway and the distance between the tangential point of trajectory S of the terminal points of the rectilinear slipway.

Referring to the previous definitions, it is easy to realise that it is sufficient to take:

$$r = R + \lambda_{\min} - \left(\text{safety dist.} + \frac{T}{2} \right) \quad (18)$$

where λ_{\min} is the minimum deviation, with a sign observed during the change of direction.

Moreover:

$$f = F_{\min} - d \cdot \cos \bar{\beta} \quad (19)$$

where:

- f is the co-ordinate for specification of the final point of the linear slipway.
- β is the guide angle when $F = F_{\min}$,
- F_{\min} is the minimum distance travelled from reference point S on the rectilinear axis, so that:

$$\lambda = \frac{L}{2} - \left(\text{safety dist.} + \frac{T}{2} \right) \quad (20)$$

Starting from the initial condition $\theta = 0^\circ$ $\beta = 0^\circ$, fixing the corner θ an interval of variation Δq , it is possible to cross (11) and (14), know $(\beta_i, \lambda_i/d)$ for every $\theta_i = \theta_{i-1} + \Delta q$, which determines the position of point U, the centre of the main landing gear. For this purpose, reference point S is positioned on the guide line based on its polar co-ordinates θ_{si} and R and thus the direction of the longitudinal axis of the aircraft is traced, based on the noted value of the guide angle β of the aircraft. Subsequently to the distance equal to the theoretical reference length, starting from S, along the axis of the aircraft, position of point U can be identified.

For every position obtained for U, starting from this point towards the internal part of the curve and perpendicular to the aircraft longitudinal axis, this leads to a distance equal to $T/2$ and the existing safety distance is verified between the rim of the main landing gear and the margin of the paved surface, and be not less than that indicated in the I.C.A.O. rules.

In the rectilinear tract, starting from the initial conditions $F = 0$, $\beta = \beta_{\max}$, $\lambda = \lambda_{\max}$, which corresponds to the position in which the reference point of the aircraft can be found between the source of the circumference arch and the beginning of the rectilinear trajectory fixing the distance F an interval of variation ΔF , it is possible through (16) and (17) to know $(\beta_i, \lambda_i/d)$ for every $F_i = F_{i-1} + \Delta F$, which determines the position of the landing gear. Based on the data, obtained in the same way, the safety distance can be verified. A further check to be made is the steering angle. In fact, the device, which regulates the direction of the nose-wheel, is built so that it works within a certain steering angle. Therefore, it is necessary to verify the steering angle of the nose-wheel, in order to follow the guide line, so that it is maintained within the limited values allowed and ratified for the considered type of aircraft. To calculate the steering angle, it is possible to apply to the owners manuals, or to use the appropriate tables, prepared by the I.C.A.O., which provide its value expressed in degrees, considering the value of β of the guide angle and the relationship of X between the theoretical reference length d and the effective distance inclusive of the nose-wheel axis and the centre of the main landing gear.

7. IMPLEMENTATION OF THE MATHEMATICAL MODEL.

The mathematical model described in the previous paragraphs was studied and implemented using computer software in order to determine the trajectory of aircraft on carriage ways of Naples – Capodichino airport and the effect that the jet motors can have on the location of the hard standings and on the vicinity of other infrastructures. This study was done in order to examine and execute the tracing of fillets planned in the Master Plan of the airport which has been prepared by the British Airport Authority and is based on previous studies done in Italy, mainly at the “Fondazione Politecnica per il Mezzogiorno d’Italia”.

To study the trajectory of an aircraft on a generic fillet, a spreadsheet was used where, knowing the geometry of the project of the guide line and the theoretical reference length of the aircraft that will be manoeuvred, it is possible to obtain the guide angle β necessary for the following tracing of the trajectory of the centre of the main landing gear. To study the trend of the main gear wheels while inside the curve, the aircraft has been geometrically planned as a T in which the wing represents the main landing gear and the core represents the theoretical reference length in which the extremity (point S) follows the guide line traced on the paved surface. The generic position of the aircraft, and thus that of T, during the turn manoeuvre, is seen in a horizontal plan, by parameters β and θ_s . Assuming the increasing variation of θ_s is equal to 5° , throughout the spreadsheet, by automating the equations (11) and (16), we obtain the respective values of β and λ . With these results, with good approximation and by using AutoCAD software, we can trace the behaviour of T where this is inserted as a slide. Inserting these graphic results on the Master Plan of the B.A.A. for Naples – Capodichino airport, simulation of aircraft movement of this type can be obtained. Such analysis has evidenced, among other things, a certain number of points of conflict, as we can see later on, which otherwise would have been difficult to have noticed.

A MD11 model-sized aircraft was used for analysis, as this can be considered without doubt, the largest aircraft for the near future to be used at the Naples airport. This aircraft, thanks to the analytical results obtained by analysing various bending radii of the guide lines and at the same time the λ swerves from the centre of the main gear, it was possible to collocate the correct position on the runway of the start line in order to offer a longer take-off run compatibly considering the effects of the jet motors have at this stage. (See fig. 6) In figures 4 and 5 studies on the trajectory have been reported, where the broadening in curve is evidenced, which is necessary when manoeuvring this type of aircraft.

The MD11 is a medium-long distance commercial freight aircraft. A summary table follows naming the characteristics of the aeroplane.

Table 1: MD 11 characteristics

Passenger capacity.....	323
Max air travel distance.....	12,987 Km
External dimensions	
Total length.....	61.21m
Wing span.....	51.66m
Total height.....	17.60m
Weight and load capacity	
Max. landing weight.....	195,044 Kg
Max. take-off weight.....	273,289 Kg
Max. weight without fuel.....	181,437 Kg
Max. fuel capacity.....	117,480 Kg
Landing gear	
Main gear inter-axis.....	10.57 m
Nose gear – main gear inter-axis.....	24.61 m
Max. turn angle of nose gear.....	$\pm 70^\circ$
Nose wheel tyre width.....	40 cm
Rear wheel tyre width.....	54 cm
External rear landing wheel inter-axis.....	140 cm
Central rear landing wheel inter-axis.....	100 cm
Nose wheel inter-axis.....	46 cm

The wake effect is considered of three distinct categories:

- a. *gust effect*, in which air turbulence caused by the rotation of rotor blades (prop wash), by helicopter motors (down wash) and by jet motors (jet wash) are indicated.
- b. *flood effect*, in which the effects of air turbulence in the form of gusts and heat are indicated;
- c. *vortex effect*, in which the effects of the air vortexes generated by an aircraft in flight are indicated (wake vortex).

The combination of these three effects is called “wake effect”.

As a general rule, winds at a speed superior to 56 Km/h are to be considered disturbing to both people on the ground as to the aircraft in flight operations. The flow of motor jet discharge can provoke air gusts with speeds many times superior to this limit, even at significant distances from the aircraft.

The intensity of the gusts depends on the thrust of the motors, which in turn depend on the operating conditions of the aircraft. On an aerodrome, critical conditions can be found at parking areas and in correspondence to the beginning of the take-off points and at the end of the runway.

Considering the weight of the aircraft, its configuration and environment factors, the maximum thrust movement from the parking area varies from 50% to 60% of the max. continual thrust (MCT), while the max. taxi force varies from 15% to 25% MCT. In relationship to such thrust values, the MD11 generates a flow that at approx.30 metres distance the aircraft reaches a speed of 180 Km/h when taxiing and 420 Km/h on take-off. Instead, a B747 at the same distance reaches a speed of 143 Km/h when taxiing and 260 Km/h on take-off. This is due to the different motor configurations.

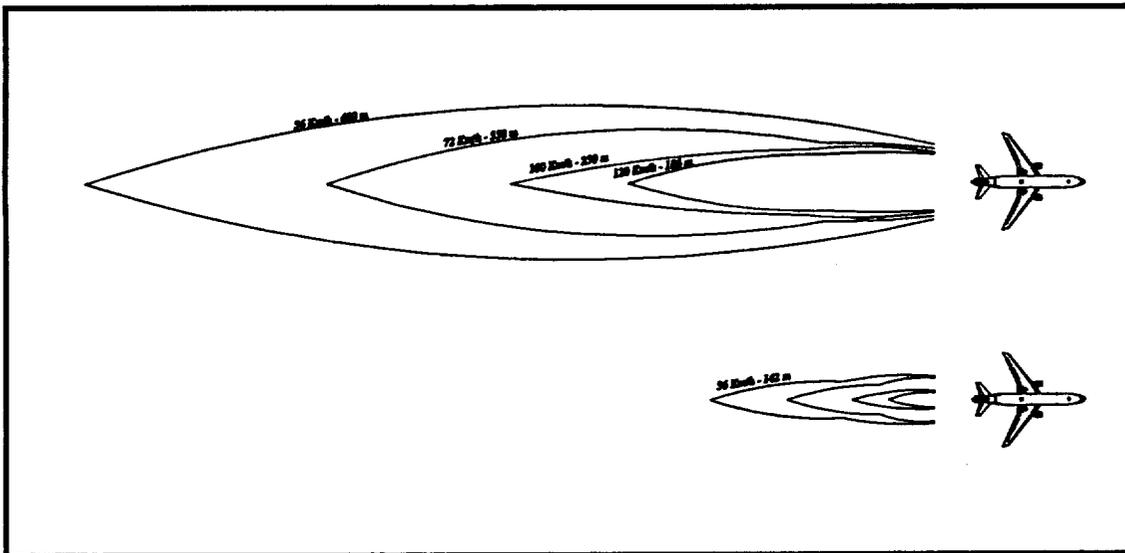


Figure 3: Speed behaviour of the air jets of the motors when taxiing and on take of.

Therefore the aircraft, from the wake point of view, that creates the greatest problems at Capodichino airport at least at the heading of the runway, is the MD11.

Table 2: Distance from the tail of the aircraft when the air jets acquire the speed of 56 Km/h.

Parked aeroplane 64 m	Taxiing aeroplane 180 m	Aeroplane in take-off 480 m
--------------------------	----------------------------	--------------------------------

The behaviour of air jets of three jet motor planes, such as the MD11, is distant from those produced by aircraft with motors positioned under the wings. This is due to the presence of central tail motors that on the MD11 are 10.00 m from the ground, with respects to wing motors which only have a distance of approx. 2.50 m. from the ground. This motor configuration produces in a vertical plan of the aeroplane, a very high area of turbulence.

Substituting in the previous slide on the measurement of T of the MD11, with the behaviour of air jets referred to in figure 3, the state of the jet motors of this aircraft in the taxi phase and when in take-off have been studied. Such study has bought about interventions not only to the apron area, by moving the stands reserved for non wide body aircraft, but also interventions in proximity to the runway heading, by adopting suitable anti-flow barriers.

In diagrams 7 and 8 we can see the graphic analysis of the effects that the MD11 jet motors have during exit and entering the runway, heading 24, after using the first right fillet, as positioned in the Master Plan of the B.A.A. of Naples Capodichino airport. By studying the fan shaped envelope at the various jet speeds, it has been observed that during the manoeuvre towards the entrance of the runway, the effects produced by the high speed of jets, are not compatible with the standards of comfort and safety for vehicles in circulation on the nearby motorway. Furthermore, by analysing the behaviour of jet speeds on a vertical plan, such study has allowed anti-flow barriers to be placed on the banks of the roadway compatible with the regulations set out by the I.C.A.O. on aeronautical obstacle limits.

By substituting again the T on the MD11 with the effective outline of the aircraft, the analysis of the movement that we obtain, as illustrated in figures 9 and 10, has allowed a study on the course of the wing tips to be done, This has been determining when planning the circulation trajectories of the parking area, the distance required when entering the runway, when positioning waiting lines on the slipways and distancing the various hard standings especially for "nose-In" type of aircraft.

Finally, it must be stressed how this study can be implemented, and not only the study on jets, but also that of the behaviour of the isophonic curves produced by motors and, therefore, the effects they have on personnel working not only in the parking areas, but also on the surrounding airport areas and on the urban environment.

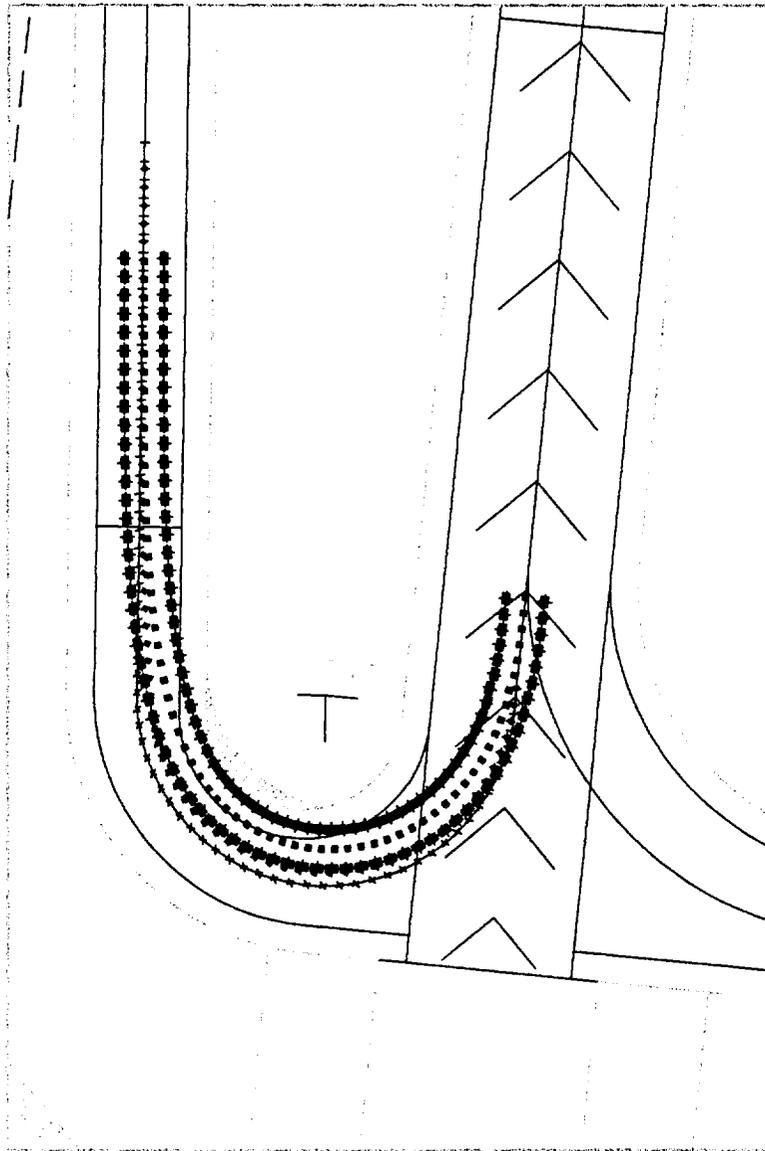


Fig. 4: Course of the MD11 undercarriage on leaving the runway heading 24

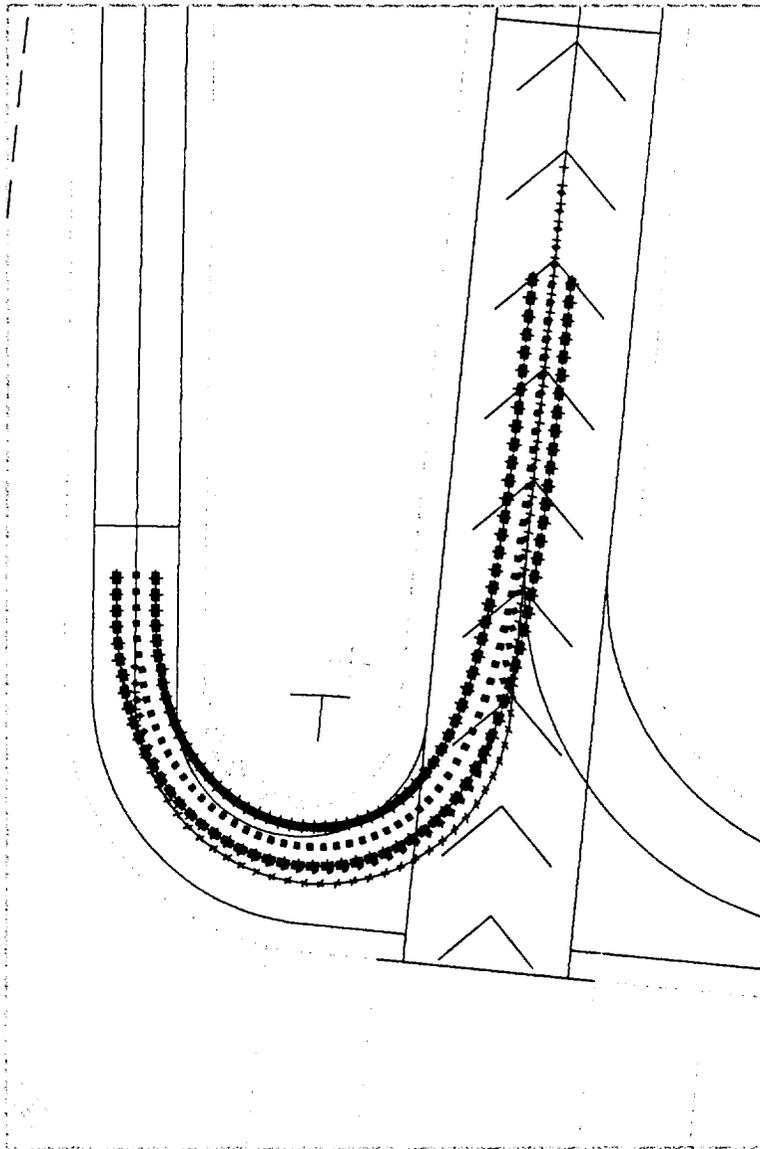


Fig. 5: Course of MD11 undercarriage on entering runway heading 24

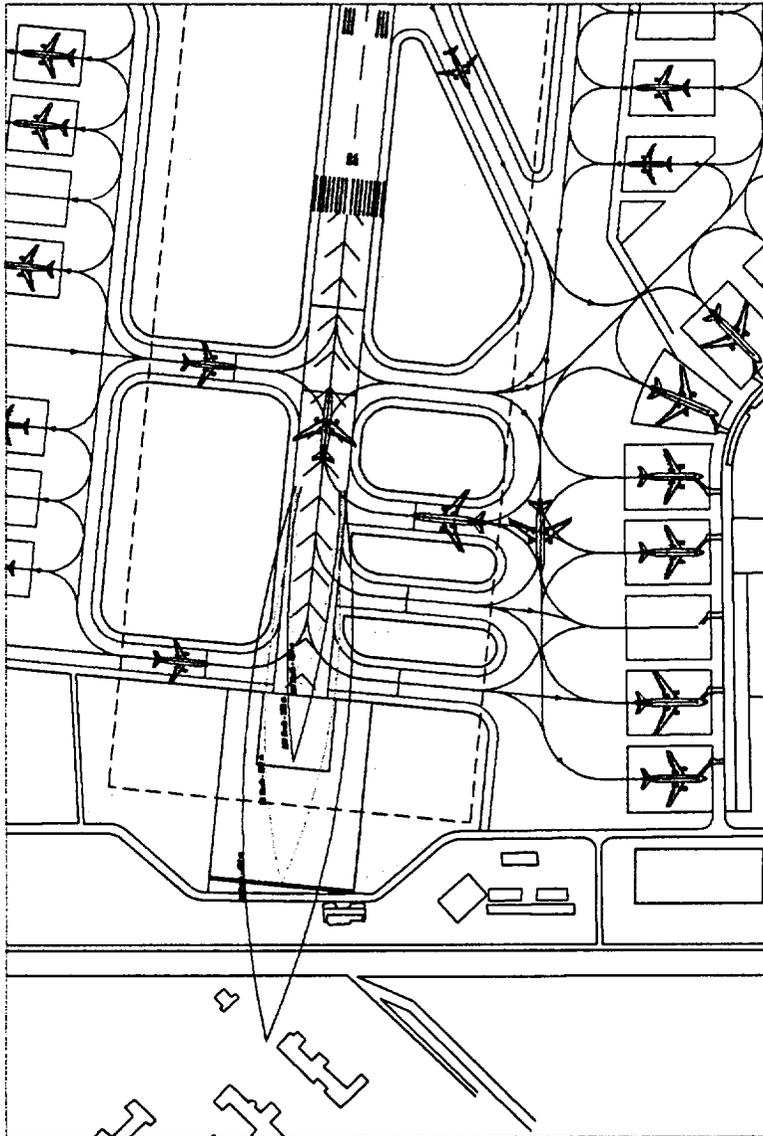


Fig. 6: MD11 in take-off heading 06

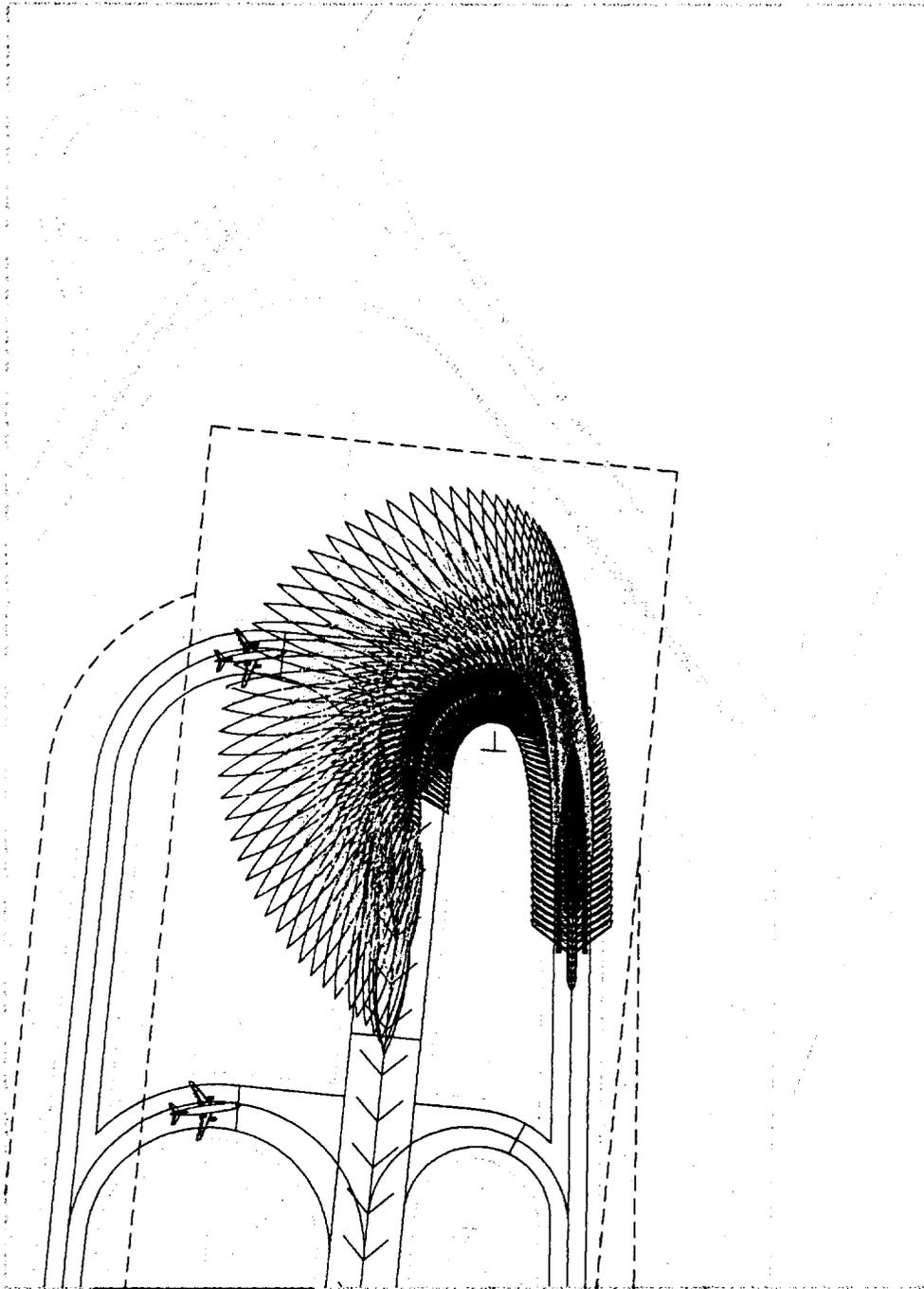


Fig. 7: Course of jet motors of the MD11 on exit of runway heading 24

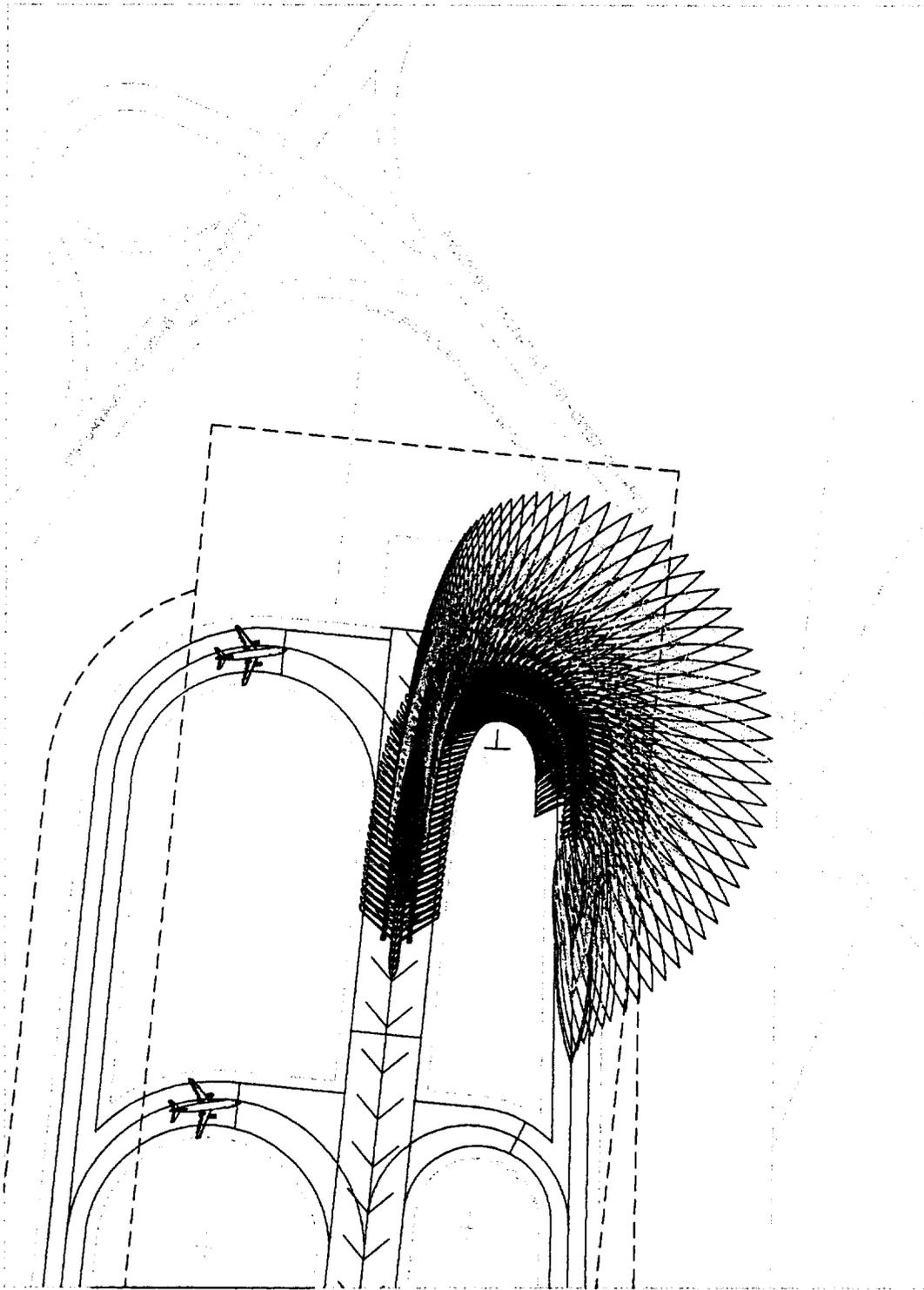


Fig. 8: Course of jet motors of MD11 on entering runway heading 24

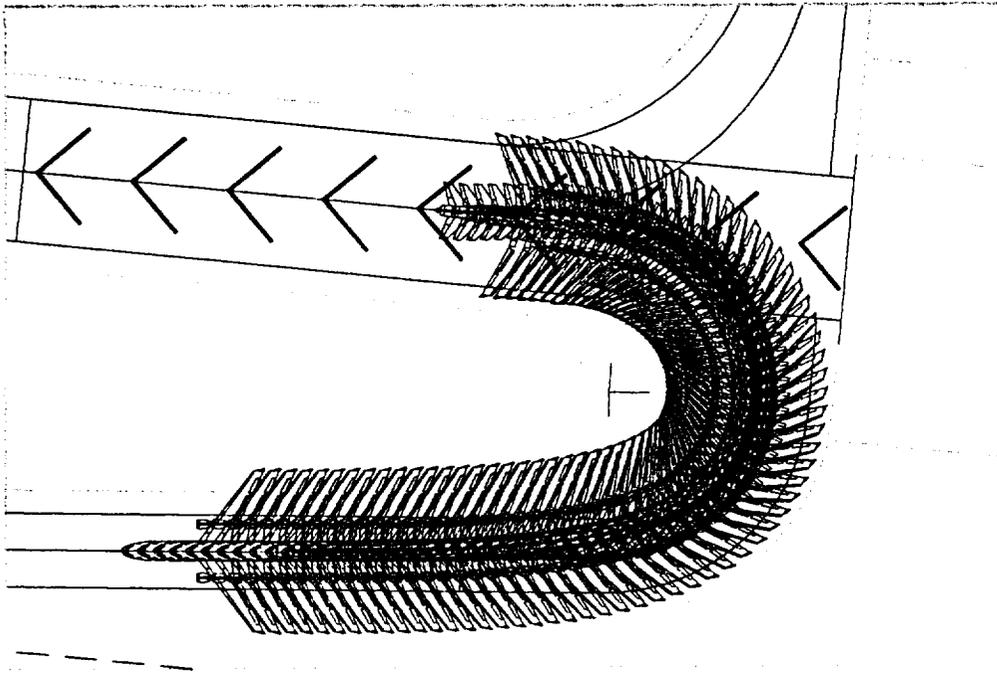


Fig. 9: Course of wing extremities of the MD11 on exit of runway heading 24

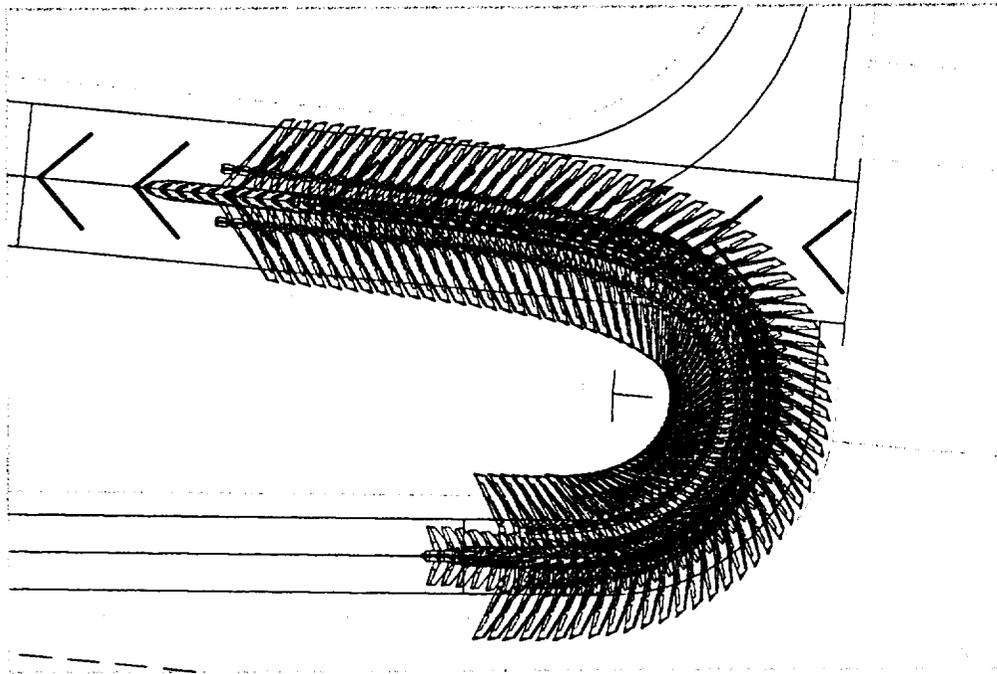


Fig 10: Course of the wing extremities of the MD11 on entering runway heading 24

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Developing an On-line Air Traffic Flow Management System

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1 INTRODUCTION

The air traffic, especially domestic flights, increase significantly in Taiwan. Average annual growth rate is about 20%. Taiwan is a small island, approximately 210 by 75 nm. There are totally sixteen commercial airports in this island. Nine domestic carriers provide 36 service routes. Most of domestic traffic is heavily distributed in the west coastal corridor. These domestic flights operate in city-pair shuttle services.

Sung Shan Airport (RCSS), located in Taipei, is the largest and busiest domestic airport in Taiwan. Currently, RCSS provides more than 500 flight operations daily and the annual passenger trips have exceeded 15,000,000. RCSS has only one single runway. The official runway capacity is 40 operations per hour. It can only offer 16 hours service due to curfew. The average annual V/C ratio is greater than 0.8. It suffers serious delays due to limited runway capacity. However, it is very unlikely to add another runway because this airport is surrounded by dense residential area. The situation gets even worse whenever the meteorological condition changes in RCSS. A 40% reduction in capacity could be resulted. The whole flight schedule could be seriously disturbed, and thus, traffic flow management (TFM) is required.

Four general procedures of TFM implemented in Taiwan include airborne holding, ground holding, en route re-routing, and restriction of metering rate. Ground holding is the most effective one since Taiwan has very limited airspace and the domestic flight times are quite short (one hour for longest). There won't be too many TFM options after the aircraft is airborne. Therefore, the coordination of ground holding and restriction of metering rate provides the backbone of TFM.

Effectiveness of ground holding policy depends on the implementation timing. This involves the recognition of congestion occurrence, its duration and seriousness. Early implementation or late release of ground holding policy or too small metering rate will cause loss of capacity and unnecessary delays; on the other hand, the airspace may be overloaded with airborne holding aircraft and extra fuel consumption is resulted.

This study develops a real time operation system to help the air traffic controllers to determine when and how to implement the strategies of ground holding policy. This operation system will be displayed by a personal computer at the air route traffic control center of Taipei FIR. It is expected to upgrade this system to a workstation and provide information to all important air traffic control facilities.

2 SYSTEM STRUCTURE

Air traffic flow management has obtained more and more attention in the world. Many countries have established their own flow management systems. For example, Europe has the flow management handled by the Central Flow Management Unit (CFMU) in Brussels. CFMU estimates the demand according to the flight plans. The supply is obtained from the capacity reports provided by each individual air traffic control center. CFMU, then, computes the slot times based on the demand and supply and automatically sends the result to each airlines[15]. The United States has the Air Traffic Control System Command Center (ATCSCC) in Herdon for handling flow management decisions. ATCSCC collects real time

information regarding weather condition, weather forecast, and traffic condition, and then estimates future traffic based on the above information[11]. Japan also established its flow management center in Fukuoka in 1994[15].

The control philosophy of the above systems may not be the same. The ATCSCC concerns with the management of airport capacity. Japanese system works with the airspace flow management. However, the main principle of these systems is to match the demand and the supply.

A system structure for flow management in Taiwan is proposed as Figure 1 after studying other flow management systems and discussing with the Taiwan CAA. The main components of the flow management system are input data, static flow distribution database, flight time estimation module, dynamic flow distribution module, capacity database and decision supporting system. This system also provides friendly interactive user interface. The Windows NT is selected as the operating environment.

The functions of this flow management system include (1)dynamically predicting the arrivals and departures in selected airports during next two hours, (2)providing the associated capacity information, (3)proposing the suggestions for ground holding strategies, (4)evaluating the impacts of each proposed suggestions, and (4)allowing the flexibility for controllers to modify the strategies and also evaluating the associated impacts.

It is noted that the Taiwan CAA currently uses the Loral system for the air traffic control automation system. Although the Loral system also has some flow management functions, the Taiwan CAA prefers developing a new system from the very beginning.

3 INPUT DATA

This flow management system needs four types of input data: (1) repetitive flight plan (RPL), (2) filed flight plan (FPL), (3) updated messages regarding flight plan, and (4) weather information. The input data provides the necessary information for predicting the flow demand and capacity supply.

RPL lists flight plan data associated with scheduled flights which are operated regularly. The information in the repetitive flight plan includes its applicable time period, days of operation, aircraft identification, type of aircraft and wake turbulence category, departure aerodrome and time, cruising speed, cruising level, route, and destination aerodrome and total estimated elapsed time.

When a flight is operated temporarily, it must obtain its air traffic control clearance by FPL. FPL has the information, such as aircraft identification, flight rules, type of flight, number and type of aircraft, wake turbulence category, departure aerodrome and time, cruising speed, cruising level, route, destination aerodrome and total estimated elapsed time, alternate aerodrome(s), etc..

The updated information regarding flight plan includes messages associated with modification, cancellation, delay, and departure. The airlines do be required to submit updated messages whenever they want to change their flight plans, but they are not required to do that immediately. For example, the delay message should be submitted when flights

would be delayed for more than one hour. Such a rule adds relatively large uncertainty for estimating departure time. The error could be as large as 59 minutes. Compared with the short domestic flight times in Taiwan, the error seems very intolerable.

The important information about weather condition includes visibility, ceiling, wind direction/speed. To predict the available capacity, it is very important to know the predicted weather status and its duration. Although the weather information is updated every 30 minutes, it does not provide any information beyond next 30 minutes.

The above data except the repetitive flight plan are transmitted by teletypewriter channels.

This study develops an expert system to screen, correct, and analyze the above data received from teletypewriter channels. Although ICAO has certain format requirements for filing the above data, it is observed that some entry of data may contain errors and need to be corrected. In addition, more types of data than needed are transmitted by teletypewriter channels. An expert system is developed to distinguish the useful data, not to miss any one, for updating system status. It is noted that even missing one single needed data could cause inaccurate prediction results.

4 FLOW DEMAND DISTRIBUTION

To dynamically represent the flow demand distribution, this study first establishes a static flow distribution database, and then, updates the (estimated) departure times with the updated messages. This study also develops a flight time estimation module. Therefore, whenever the departure time is known, the arrival time can be projected based on the estimated flight time.

The static flow distribution database is established based on RPL data. The static flow distribution database has the total number of arrivals and departures for every fifteen minute time interval at each individual airport. Most of domestic flights are included in RPL data. Basically, the static flow distribution database can roughly represent the demand distribution pattern. However, some flights may be operated temporarily and some may be delayed, or canceled, and thus, the flow distribution pattern changes accordingly. Such a problem gets even serious when the capacity is reduced.

In stead of estimating the flight times by trajectory analysis, this study develops a flight time database using the empirical SAR tape data to reflect the local characteristics. It is noted that the flight time function should be simple enough for easy application but still provide enough precision.

It is observed that the origin-destination pair, aircraft type, airlines and cruising level may affect the flight times. These factors may have some correlation. For example, the cruising level is usually related to the origin-destination pair and aircraft type. To avoid the homoscedasticity problem and to keep the flight time function simple, this study tries to use as few factors as possible. The flight times are grouped by O-D pair first. The minimum, maximum, average, and standard deviation are computed for each group. If the standard deviation of each group is not small enough, each group would be further divided by another factor. The results show that the origin-destination pair and aircraft type are two major

influential factors for flight times. After grouping by O-D pair and aircraft type, most groups have standard deviation less than one minutes.

5 CAPACITY DATABASE

The major weather factors affecting airport capacity are visibility, ceiling, and wind direction/speed. It is well known that the capacity under IMC operation may be significantly reduced compared with that under VMC operation. The choice for IMC or VMC operation depends on the visibility and ceiling. Most of domestic airports have only one runway in Taiwan. The runway direction under operation may be switched when wind direction/speed changes. Different runway direction has different requirements regarding separation, visibility, and ceiling, and thus, has different capacity. The capacity database establishes various capacity values associated with visibility, ceiling, and wind direction/speed for each airport. Table 1 shows the available capacity under various weather situations for Sung Shan Airport. Therefore, whenever the weather condition is known or forecast, the available capacity for each airport can be determined or predicted.

To determine which strategy should be implemented for air traffic flow management, the key information includes current capacity and predicted capacity for the entire flow management time horizon. Therefore, it is necessary to obtain not only the weather status, but also how long the weather status will last. It is noted that the weather information obtained from the teletypewriter channels does not provide the predicted weather status beyond the next 30 minutes and it doesn't specify the effective time period of provided weather status either. Such a deficiency cause a problem in determining the available capacity beyond the next 30 minutes, and thus affect the stability of predicted capacity.

6 DECISION SUPPORTING SYSTEM

The decision supporting system is to help air traffic flow management commander to decide when to impose the flow control and how to do it. To determine the timing for implementing flow control, it is necessary to know when the congestion occurs and how serious it is.

Several indices are computed to indicate the occurrence and seriousness of the congestion. These indices include the congestion occurring time period, its duration, the maximum queue length, and the total waiting time. The notations used to compute these indices are defined in the following:

D_{at}^k : number of flights which are scheduled to depart at Airport K in Time period t and has already airborne.

D_{pt}^k : number of flights which are scheduled to depart at Airport K in Time period t but has not taken off yet.

A_{at}^k : number of flights which are scheduled to arrive at Airport K in Time period t and has already airborne.

A_{pt}^K : number of flights which are scheduled to arrive at Airport K in Time period t and has not taken off yet.

C_t^K : the available capacity of Airport K in Time period t.

m: the time period with the maximum queue length

W: the total waiting time

TU: the length of a time period. This study let TU = 15 minutes.

These indices are computed as follows:

1. The congestion occurring time period, T:

The congestion occurs when the demand exceeds the supply.

$$D_{aT}^K + D_{pT}^K + A_{aT}^K + A_{pT}^K > C_T^K$$

2. The congestion duration, n time periods:

$$\sum_{t=T+1}^{T+n} A_{at}^K + A_{pt}^K + D_{at}^K + D_{pt}^K \leq \sum_{t=T+1}^{T+n} C_t^K$$

3. The maximum queue length:

$$\max_m \left[\sum_{t=T+1}^{T+m} (A_{at}^K + A_{pt}^K + D_{at}^K + D_{pt}^K - C_t^K) \right] \quad m=1,2,$$

4. The total waiting time:

$$W = \sum_{j=1}^{n-1} \sum_{t=T+1}^{T+j} (A_{at}^K + A_{pt}^K + D_{at}^K + D_{pt}^K - C_t^K) \times TU$$

This study suggests to implement flow control only when the congestion is expected to last more than certain time periods. It is noted that the capacity is not a rigid value. The official capacity just represents a conceptual number. The air traffic controllers have the capability to smooth the traffic if the congestion is not very serious. Therefore, it is not necessary to implement flow control immediately when the congestion just occurs. Currently, this study recommends that flow control is needed when the congestion duration n is greater than 2. Further evaluation is helpful for validating such a recommendation.

At first, this decision support system tries to develop an algorithm to suggest which aircraft should be delayed on the ground and for how long. This algorithm will be developed based on the analysis of ground holding policy. The ground holding policy problem has been well discussed in [2,3,5-14]. However, it is necessary to take some modifications to apply the ground holding theory in real time situation.

The problems involved in on-line application are the data availability, its accuracy, and precision. The time ready and intended for take-off is the required input data for ground holding policy problem. However, it is very difficult for the operation system to obtain this input data. Although the operation system can obtain the scheduled departure time from the flight plan, the flight may not be ready and intended for take-off by that time. That is, the scheduled departure time only provide rough estimation for the ready and intended for take-off time. The error between the scheduled departure time and the ready and intended for take-off time could be as large as 59 minutes since the airline is required to submit a delay message only when the flight will be delayed for more than one hour. Such an error causes a problem for managing air traffic flow in Taiwan due to relative short flight times.

Such a problem prohibit this study from developing an algorithm for managing the departure sequence and timing. To improve this problem, it is suggested that the flight should apply and obtain its air traffic control clearance via datalink instead of voice. The air traffic control clearance is the permission for a flight to join the queue for take-off. The time of filing application for clearance can be treated as the time ready and intended for take-off. Currently, the application is filed via the voice communication channels, which prohibits the flow management system from acquiring such information. Datalink may be helpful to pass information to the flow management system.

The ground holding decision will be affected by the airborne cost, ground cost and chain effect. These cost components are aircraft type related and also affected by flight load factor. The chain effect depends on airlines' own flight routing and scheduling plan. These data may not be available or may not be accurate while operating in real time situation.

Due to the limitations mentioned above, this study currently decides to provide the rough departure rate for flow management . It is noted that whenever the precise ready and intended for take-off time is available, the decision support system can be easily modified to provide the suggested departure sequence and timing, . Although this system will provide some flow control suggestions, the flow management commander can always overwrite the system suggestions . The flow management commander can propose various flow control strategies. This system can even evaluate the impact of each strategy

7 FIELD TEST

Currently, the main part of this system has been completed and is under field test. Some problems are observed about the quality of input data. These problems are listed as follows:

1. The input data may not provide correct information. Sometimes, the airlines do not submit updated messages, as required. Thus, the decision support system cannot present the real condition correctly. It is observed that some flights has taken off without sending any departure message or some flights has been canceled without sending any cancellation message.
2. The input data is not precise enough for estimating the departure time and the arrival time. The airlines do not need to submit any delay message unless the flight is expected to be delayed more than one hour. That is, the possible error of estimated flight times can be as

large as 59 minutes. Such a problem is especially serious in Taiwan because the domestic flight time is less than one hour.

3. The input data does not provide enough information for predicting the capacity. The input data only provides weather information for the next 30 minutes. This enforces the system to use some default values for predicted capacity beyond the next 30 minutes, and thus, may generate some prediction errors.

To avoid the incorrect input data (problem 1) affects the system performance seriously, this study decides to automatically cancel a flight when its delay exceeds certain limit. Currently this study suggests to use 60 minutes as the limit. However, the user is allowed to specify any number for this limit. Theoretically, the predicted flow pattern won't be accurate when the limit is too small or too large. The appropriate number could be determined based on the empirical delay distribution

Most of functions of the flow management system has been tested comprehensively, and the results show that it works quite well. The decision support system is also tested. However, it is suggested to develop a simulation model to evaluate the performance of ground holding algorithm since the real world cannot provide a good environment for conduct a comprehensive test.

8 CONCLUSIONS AND RECOMMENDATIONS

This study tries to develop a real time decision support system to decide when and how to do flow control. This system can dynamically display the flow demand and capacity of certain airport for any selected time period. Based on the information of demand and capacity, this system determines whether the congestion occurs or not and its impact. If the congestion is expected to last more than certain time periods, the system will send a warning signal and also give a suggestion about ground holding strategy. However, this system does not enforce to implement the suggested strategy. The flow management commander can always modify the strategy or propose a new one. This system will evaluate the performance of each strategy and let the commander make the final decision.

This system is under field test currently. The results show that this system works quite reasonable. However, the quality of input data will affect the system performance significantly and needs to be further improved.

It is recommended to incorporate the input data from the radar data processor (RDP). Currently, to obtain a workable system, this study does not intend to integrate the data from the complicated RDP system. The RDP can provide information about in-aviation aircraft status, including its real time position, cruising speed and cruising level. These data are very helpful for obtaining precise estimated arrival time.

This system could be extended to have interaction with the airline operation center (AOC). This can provide the AOC with the real time information about demand and capacity distribution. It is helpful for the AOC in making decision regarding flight dispatching and scheduling. The AOC can also provide the newly changed flight plan information to this system. Therefore, the system can update its status efficiently. In addition, this system can

be modified to provide passengers with the updated flight estimated departure or arrival times.

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Figure 1 Structure of Flow Management System

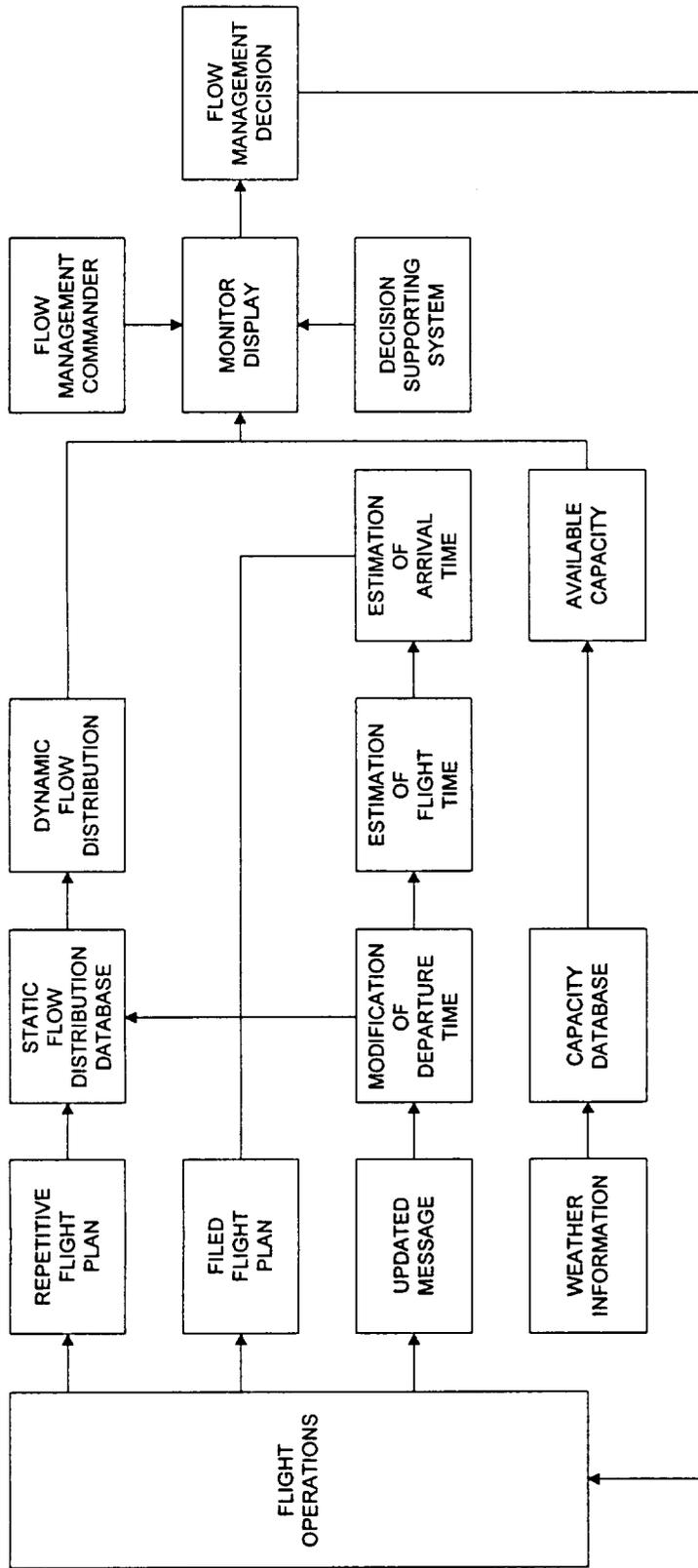


Table1 Available Capacity for Sung Shan Airport

Wind Direction & Speed	RWY in Use	Visibility(m)	Ceiling Height	Capacity Operations/hr
170° ~350° Speed>10KT	28	>5000m	>3000ft	40
		4800~5000m	<3000ft	20
			>3000ft	20
		<4800m	<3000ft	20
Otherwise	10	Take-off >500 & Landing >800	>3000ft	0
			<3000ft	0
				40

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